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PROGRAM OF APPLIED RESEARCH IN PERSONAL DEFENSE WEAPON SYSTEM

Dunlap and Associates, Incorporated

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The primary objective of this study was the acquisition of experimental data describing how human performance with a personal defense weapon is affected by: target size (range), target presentation characteristics, weapon configuration and human capabilities and limitations. A secondary objective was the development, fabrication and installation of an equipment system capable of supporting data collection requirements.

The experiment was designed to obtain data concerning the effects of target, weapon and human performance variables on aiming and firing efficiency with a weapon having the basic configuration of a Caliber .45 Automatic Pistol M1911A1.

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20. Abstract.

Results indicate that the baseline configuration having a short, light trigger pull with a moderate grip angle using the 2-hand hold produces the most efficient effects for the weapon under investigation. Target variables, while indicating a variety of significant effects, did not, in general, complicate these conclusions.

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PROGRAM OF APPLIED RESEARCH IN PERSONAL DEFENSE WEAPON SYSTEM

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

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EXECUTIVE SUMMARY

The research reported here was performed for the USA Human Engineering Laboratory, Aberdeen, Maryland, under Contract No. DAAD05-73-C-0518.

The study was prompted by the need to provide certain Army personnel with a more effective personal defense weapon (PDW). The Caliber .45 Automatic Pistol M1911A1 is their current PDW. This study is conceived as the first of a series of studies to investigate variables that affect the man-weapon system performance. Certain weapon variables, including recoil, blast and center of gravity, were held constant (i.e., were not tested) in this study at the instructions of the USA Human Engineering Laboratory. This was done so that the effects of specified non-firing parameters of PDW design could be investigated free of the confounding or masking effects of variables such as those listed above.

The primary objective of this study was the acquisition of experimental data describing how human performance with a personal defense weapon is affected by: target size (range), target presentation characteristics, weapon configuration and human capabilities and limitations. A secondary objective was the development, fabrication and installation of an equipment system capable of supporting data collection requirements.

The experiment was designed to obtain data concerning the effects of target, weapon and human performance variables on aiming and firing efficiency with a weapon having the basic configuration of a Caliber .45 Automatic Pistol M1911A1.

Equipment was developed to provide for testing various levels of trigger pull force, trigger slack, grip angle, target range, target motion and target exposure time. Another variable tested in this study was 1- versus 2-hand hold. One combination of trigger pull force, trigger slack and grip angle was identical to the characteristics of the Caliber .45 Automatic Pistol M1911A1 and served as our baseline configuration. A sample of 16 subjects was tested on these variables to determine their effect on aim dispersion, percent hits, hit frequency and time to first shot.

Results indicate that the baseline configuration having a short, light trigger pull with a moderate grip angle using the 2-hand hold produces the most efficient effects for the weapon under investigation. Target variables, while indicating a variety of significant effects, did not, in general, complicate these conclusions.

It is suggested that other variables such as center of gravity and trigger design, as well as intermediate levels of the variables investigated in this study be further investigated to determine more accurately their impact on firing efficiency.

I. INTRODUCTION

A. General

The research reported here was supported by the U. S. Army Human Engineering Laboratory, Aberdeen, Maryland, under Contract No. DAAG 05-73-C-0518. Mr. James P. Torre, Jr., of U. S. Army Human Engineering Laboratory served as Contract Technical Supervisor for this research program.

B. Background

Authorities in the U. S. Army believe that there is a continuing requirement for a personal defense weapon for military personnel in close combat situations who, because of their duties, cannot or do not normally carry a rifle. The present standard Army personal defense weapon (PDW) is the Caliber .45 Automatic Pistol M1911A1 which was adopted in 1926. While this weapon has many fine characteristics of serviceability, soldiers have difficulty with it in achieving hits. As a consequence, the Army has initiated a number of programs aimed at the development of a more satisfactory PDW. The research reported here is numbered among these various development programs.

The current technical approaches to the development of the PDW have been primarily aimed at the provision of multiple projectiles per trigger pull to obtain higher hit probabilities and to design the weapon to allow the natural or instinctive pointing capabilities of shooters to be utilized to the fullest extent. Other investigators have looked at the problem from a point of view of training shooters in better firing techniques. Fundamental changes are taking place in the training methods and field firing techniques for hand guns. Although it was long recognized in law enforcement circles that it was very rare in a close combat situation that there was time available for the offhand stance, eye-level hold, single-action delivered fire of the target range, this was the method that was long taught. In recent years strong efforts have been undertaken to teach "combat" hand-gun shooting. For example, the Royal Canadian Mounted Police are trained to fire their service revolver double-action only, using 2-hand hold either at hip level for short ranges (out to ten meters) or at eye-level for ranges to 25 meters. The only single-action fire, still two hands, is reserved for beyond 25 meters. This type of firing is far removed from the target range where the objective is to obtain small groups of shots correctly placed on a target for high numerical scores.

One aspect of the problem of PDW design requiring further investigation is the interaction effects of shooters' capabilities with weapon characteristics and combat environments. Such endeavors fall into the category of human engineering, an approach which has been applied frequently to the development of simple and complex weapon systems. At present, substantive human engineering data on various non-firing parameters of PDW design are lacking, since their effects on performance are often masked or confounded by the effects of more potent firing variables operating in actual firing situations. Therefore, laboratory studies in which various firing parameters can be controlled are required to provide information on performance effects of certain design variables which are not easily measured in the field. Many variables can affect human performance in PDW shooting and all of these variables cannot be studied with one research project. Figure 1 is a list of some of the experimental variables that are relative to the study of human performance with PDWs. Therefore, a series of studies (each more definitive) will be required before human engineering data can have its full impact on PDW design. This study is the first of those and consequently treats only the more fundamental issues of human performance related to PDW shooting.

Target Size	Target Presentation Characteristics	Weapon Configuration	Human Performance Requirements
Range 5-50 meters Aspects Front Side	Exposure Time 1-10 seconds Stationary Standing Kneeling Crouch Prone Moving Running Up-right Crouching Walking Up-right Crouching Direction Laterally Right vs. Left Approaching Receding Changing Amount of Exposure Entire body Part of body (Use of cover)	Type of Operation "Automatic" "Revolver" "Saw Handle" Grips Angles Shapes Modifications for hold Weight Mass Distribution Trigger Design Slack Pull Distance Force Sights Conventional Rib Optical Impulse Noise	Method of Operation One hand Two hand Firing Position Stationary Standing Kneeling Prone Moving Walking Running Sighting Conventional Rib Optical

Figure 1. List of Some Experimental Variables and Subvariables Relevant to the Study of Human Performance with Personal Defense Weapons.

C. Project Objectives

Since this study is planned as the first of a series, its objectives are both technology and equipment oriented. These objectives are listed below:

- Primary objective: The acquisition of experimental data which describes how human performance with PDWs is affected by the following variables
  - Target size (range)
  - Target presentation characteristics
  - Weapon configuration
  - Human capabilities and limitation
- Secondary objective: The development, fabrication and installation of an appropriate system of equipment and instruments to support the data collection requirements of this study and to the extent possible, the requirements of future studies.

D. Scope of Study

The number of variables suggested in Figure 1 is so large that it is uneconomical and inefficient to attempt to examine all variables simultaneously under one contract. Therefore, this study is limited to the investigation of only the few levels of variables listed in C above.

II. CONDUCT OF THE RESEARCH PROGRAM

A. General

This project was accomplished as a team effort involving personnel from three companies: Dunlap and Associates, Inc., Darien, Connecticut; Reflectone, Inc., Stamford, Connecticut (a subsidiary of Dunlap and Associates, Inc.); and Bellmore-Johnson Tool Company, Hamden, Connecticut. Dunlap and Associates served as the prime contractor and was responsible for the overall effort and specifically the research design, data collection and analysis. Responsibility for the test apparatus laid jointly with Reflectone, Inc. and Bellmore-Johnson Tool Company. Bellmore-Johnson was responsible for providing the PDW test devices and certain other hardware items. Reflectone, Inc. was responsible for the design of the electronics and control systems and the integration of the entire system of instrumentation.

B. Project Tasks

To complete this study, five major tasks had to be accomplished. These were:

- Develop test plans
- Design and fabricate test equipment
- Data collection
- Data reduction and statistical analysis
- Prepare final report

These tasks are quite similar to those of any other experimental research; however, to accomplish these tasks, many subtasks had to be completed. The subtasks are listed here to give the reader a feel for the number and variety of tasks involved in such a project. More importantly, however, this listing is intended to benefit those researchers who may wish to undertake similar programs. Figure 3 is a list of the subtasks required to complete the study. This list is organized under the headings of the five primary project tasks listed above. However, the order in which the subtasks appear does not necessarily reflect the order in which they were accomplished.

Develop Test Plans

1. Develop Experimental Design
2. Determine the Specific Data to be Analyzed
3. Determine Data Reduction Methods
4. Develop Plans for Recruiting and Selecting Subjects
5. Develop Plans for Training Subjects
6. Develop Instructions for Training and Experimentation
7. Determine Rate and Conditions of Subject Pay Motivation

Design and Fabricate (Acquire) Test Apparatus

1. Design Test Weapon(s) PDW
2. Determine Proper Filter for PDW
3. Fabricate Bench Rest (for calibration of PDW's)
4. Design Turn Table Assembly and Controls
5. Design I.R. (Infra-Red) Control Circuitry
6. Design Master Control Unit
7. Select and Acquire Timer/Printer
8. Design Printer Buffer and Interface
9. Test IR LED's
10. Design IR Spot Generator (Lens System)
11. Determine Optimum Conditions for IR Trace
12. Obtain Operational Movie Camera
13. Obtain Correct Projector Lens
14. Obtain Projector Shutter Assembly
15. Determine Proper Filters for Camera and Projector
16. Determine Geometry of Test Situation
    - "Weapon" (PDW) to screen distance
    - Curvature and Dimensions of Screen
17. Obtain Projection Screen
18. Design Target Slides
19. Design Calibration Target
20. Design ID Slides for Test Trials
21. Obtain Visual-Choice Reaction Time Apparatus
22. Assemble and Test Entire Apparatus System
23. Make Equipment Adjustments as Required

Data Collection

1. Preparations for Testing
    - Develop final detailed training and testing protocols
    - Determine specific data analysis procedures
    - Establish hardware/software requirements to accomplish analysis
    - Dry-run representative experimental trials
    - Recruitment, screening and training subjects
2. Conduct Experimental Trials
    - Re-run "bad" trials

Data Reduction and Statistical Analysis

1. Reduce Data
2. Test Reduced Data for Acceptability
3. Analysis of Data
    - Develop computer coding
    - Data storage
    - Develop programs for analysis
    - Analyze data
4. Interpretation of Results

Prepare Final Report

1. Prepare Draft of Report
2. Revision of Draft Report
3. Submit Final Report

Figure 3. List of Project Tasks and Subtasks

III. RESEARCH PLAN

A. General

The research plan for this project was designed to obtain, with maximum economy, reliable and accurate data concerning the possible effects of specified target, weapon and human performance variables on aiming and firing efficiency with a weapon having the basic configuration of a Caliber .45 Automatic Pistol M1911A1. This section is limited in scope to the description of the software aspects of planning. A description of equipment, facilities, procedures and protocols will follow this chapter.

B. Independent Variables

The broad scope of variables that could be topics for this investigation has already been suggested in Figure 1 (Chapter I, D.). For reasons of economy the investigation in this study is limited to the seven variables identified in the original statement of work, and has further restricted to two or three the number of levels of each of the variables to be studied. These restrictions are necessary from a point of view of economy, time and manageability of raw data. Table 1 shows the seven independent variables chosen and the several levels of each that were investigated in this study.

The apparent wide ranges in the values selected for levels of variables is deliberate. Since only two levels were planned for six of the variables, it was reasoned that wide differences in values would enhance the sensitivity of the experiment and, therefore, indicate the direction additional research might take if refinement appeared warranted.

For convenience, hereafter, we will refer to the trigger slack of 0.03 inches and 0.47 inches as the short pull and long pull conditions, respectively. In a similar manner, we will refer to the trigger pull forces

Table 1. Independent Variables and the values of their several levels.

Independent Variables	Levels of Variables		
Trigger Slack	.03"*	.47"	—
Trigger Pull Force	5 lbs.*	12 lbs.	—
Grip Angle	Moderate 17.5° *	Extreme 30°	—
Target Size (Range)	10 meters	25 meters	40 meters
Target Motion	Stationary	Moving 15ft./sec.	—
Target Exposure Time	2 sec.	4 sec.	—
One/Two Hand Hold	One Hand	Two Hands	—

*Actual values for the Caliber .45 Automatic Pistol M1911A1.

of five pounds and twelve pounds as the light pull and heavy pull, respectively. Actually, because a trigger assembly must have both a slack and a pull force, references in the text will describe a trigger assembly in terms of both variables, e.g., an assembly having a short (0.03 inches) pull and a heavy (twelve pounds) pull force will be referred to as a short, heavy pull.

It should be noted that the Army desires comparative data on the test weapons used here and the Caliber .45 Automatic M1911A1. Because of this requirement, the basic configuration, weight and balance of the M1911A1 has been used as the "model" for our test weapons, and those aspects of the M1911A1 have been held constant across all experimental conditions. From Table 1 it is clear that three of the independent variables; trigger slack, trigger pull force, and grip angle, are concerned with weapon configuration. The variable levels marked in Table 1 by asterisks are the values representative of the Caliber .45 Automatic Pistol M1911A1. Thus, we are able to obtain baseline data on the M1911A1 for comparison against other weapon configurations. The value for trigger slack of 0.03 inches is within allowable tolerances for new weapons as they come off the assembly line. The value for trigger pull force of five pounds was obtained from Field Manual FM23-35 (1960). The value of the grip angle of 17.5 degrees was obtained by measuring an actual weapon. The angle reported here is defined as the acute angle formed by the forward edge of the grip and a line perpendicular to the center line of the barrel. For convenience, hereafter, the grip angle representing the M1911A1 will be referred to as the moderate grip angle. This extreme grip angle represents the typical angle of the Luger pistol.

Three levels of target size or range were selected to represent target engagements at near, medium and long ranges. The near range value of 10 meters was chosen because space limitations of our laboratory prevented simulation of moving targets at ranges as close as 5 meters. The 25 meter and 40 meter values were selected as being convenient and representative of mid and long-range situations.

The value of 15 feet per second for the moving target condition is a speed equivalent to a 6-minute mile rate and is considered representative of speeds men might attain over rough terrain.

The values of two and four seconds for target exposure time were selected because anecdotal evidence existing in the open literature for close combat or pistol confrontation leads us to believe these are realistic exposure times.

The 1- and 2-hand holds were specified as independent variables in the contract.

C. Measures of Performance

The performance measures or dependent variables obtained for each trial in this study include the following:

- Number of hits per trial
- Percent hits per trial
- Time to first shot fired
- Time to first hit
- Horizontal aim dispersion (standard deviation)
- Vertical aim dispersion (standard deviation)

D. Subjects

1. General

The contract specified that test subjects be males between the ages of 17 and 34 years and have binocular vision of 20/40 or better, with or without correction. Further, the subjects should be able to perform a perceptual motor skill to a criterion level. For this study it was felt that the subjects should generally fit the description of U.S. Army recruits in terms of age, race, education and anthopometric dimensions. The source reference used for the demographic characteristics of the U.S. Army recruits was White and Churchill (1971). Subjects were recruited from local area colleges, high schools, volunteer fire departments and C.T.E. programs. Visual acuity, and a visual choice reaction time test were administered to candidate subjects and personal and demographic data were also obtained.

2. Description of the Subject Sample

There were 16 test subjects in this study. This sample size is considered sufficient to meet the requirements of the experimental design. Nineteen candidates were screened of which 16 completed the experimental program. Of the remaining three, two failed to meet the visual acuity standard and were dismissed. The remaining candidate was screened and trained but failed to report for his experiment session and was, therefore, dropped from the sample.

Subject motivation was obtained through a monetary stipend of $50. This fee was paid to subjects who completed a training and orientation session and two experiment sessions. The total time spend by each subject in both training and testing varied from eight to ten hours, reflecting some variation in procedural efficiency. Some subjects had to return for a fourth session to rerun some trials where data were lost either through camera malfunctions or procedural errors. In these cases subjects were paid $5 per hour. Most of the rerun sessions lasted 20 minutes or less and the subjects were paid $5 for their trouble. One subject's rerun session required approximately one and one-half hours, and he was paid $10.

In general, the average U.S. Army recruit and typical basic trainee can be described as being 20.8 years old, is white (14.6 percent are Negro), is a high school graduate, is 68.71 inches tall and weighs 159.1 pounds with a hand length of 7.49 inches and whose hand breadth is 3.5 inches. Table 2 is a tabulation of the demographic characteristics of the sample of subjects used in this study.

From Table 2 it can be seen that our sample of subjects, while not strictly representative of the Army population, is certainly similar with respect to age, ethnic balance, and level of education. Physically, our subjects are bigger and heavier than recruits. The mean height and weight of the sample represents approximately the 78th percentile of recruits. The subjects also have large hands, equivalent to the 75th percentile on length and 87th percentile on width. While our subjects are physically larger than the population described by White and Churchill (1971), the differences are probably not as great as they may appear on the surface. White and Churchill, when comparing data from surveys taken in 1946 and 1966, noted that while there were small increases in average body dimensions, there were upward shifts

Table 2. Demographic Description of Subjects

Subject Code	Age	Race	Educ. Level Yrs.	Vis. Acuity	Height (inches)	Weight (lbs.)	Hand Meas. Length	(Inches) Width
A	18	N	12	20/40	72.8	218	8.12	3.90
B	19	N	12	20/40	72.8	172	8.25	3.90
C	17	W	12	20/20	69.8	167	7.63	3.78
D	18	W	12	20/20	69.8	148	7.50	3.78
E	19	N	12	20/30	71.8	143	7.87	3.50
F	21	W	12	20/20	71.8	187	7.13	3.75
G	20	W	13	20/20	73.8	177	7.87	3.75
H	20	W	14	20/20	67.8	151	7.63	3.50
I	17	PR	12	20/20	70.8	158	7.87	3.62
J	22	W	12	20/25	71.8	172	7.87	3.50
K	18	W	12	20/25	70.8	207	7.31	3.87
L	21	W	12	20/30	72.8	222	8.12	3.87
M	21	W	11	20/20	69.8	202	7.63	3.87
N	18	W	11	20/30	73.8	207	7.63	3.75
O	18	W	13	20/30	69.8	172	7.63	3.62
P	21	W	11	20/40	68.8	138	7.63	3.62

in percentile values for body dimensions. White and Churchill go on to say that these shifts are noticeable particularly in the higher percentile values at the upper end of the distribution of body dimensions in the Army population. For example, in 1946, 5 percent of the population were taller than 72.6 inches in height, while in 1966, 7 percent of the population were taller than 72.6 inches. Thus, each generation seems to produce more "big" men than the previous generation. Our sample of subjects drawn in 1974 is eight to nine years younger than the sample surveyed by White and Churchill in 1966. Thus, while our sample of subjects is large compared to Army recruits in 1966, they are probably not quite as large percentilewise if we could compare them to a sample of 1974 recruits.

E. Experimental Design

1. Target Conditions

Twelve target conditions were defined for this study, representing all possible combinations of target variable levels (3 ranges by 2 exposure times by 2 motion conditions). These 12 target conditions are described and represented by the last 12 columns in Figure 4, which depicts the entire matrix of experimental variables in this study.

Variations in target size simulated a standard E-type silhouette target at distances of 10, 25 and 40 meters. Image size and vertical placement on the screen were determined in accordance with what a standing man of average height would see if an E-type (40-inch high) target were placed at the above distances on a level field.

For each simulated target distance, both stationary and moving target conditions were presented. The stationary mode consisted of the appearance of the target at any of three preset fixed positions. One of these was the center of the subject's field of vision on the horizontal plane, one 30° left of center and the third 30° right of center. The position at which the target occurred on a given trial was random with the restriction that within any given test session (containing six stationary presentations) targets appeared twice at each of the three fixed positions. The moving target presentation mode consisted of a target moving either from left to right or from right to left across the screen at a simulated constant rate of 15 feet per second for the specified exposure interval. For each moving target condition a vertical bar of green light was projected at one of a number of possible positions, indicating to the subject the point at which the target image would disappear. Images appeared to the left or right of the light bar (with equal probability) at distances determined by the simulated motion and exposure interval specified for the particular target condition. The target traveled toward the light bar at the specified rate until it touched, whereupon it disappeared. This served to inform the subject as to how much time was available for him to score hits. It should be noted that under stationary target conditions no such cues to exposure time were available.

Every target condition described above was presented at each of two levels of exposure time--2 seconds and 4 seconds. This results in 12 distinct target presentation trials, all of which were presented to the subject in any single experimental session, with presentation order being randomized for each session.

2. Weapon and Human Performance Characteristics

Each session involved a different combination of weapon and human performance characteristics. As shown by Figure 4, all possible combinations of the following variables were tested:

- Two grip angles
- Two levels of trigger slack
- Two levels of trigger pull force
- One versus two-hand hold

Grip Angle	Trigger		Hand Hold	Target Variables											
				10 meters				25 meters				40 meters			
				2 sec.		4 sec.		2 sec.		4 sec.		2 sec.		4 sec.	
	Slack	Force		Sta.	Mov.	Sta.	Mov.	Sta.	Mov.	Sta.	Mov.	Sta.	Mov.	Sta.	Mov.
Mod.	Long	Lt.	1												
			2												
		Hvy.	1												
			2												
	Short	Lt.	1												
			2												
		Hvy.	1												
			2												
Ext.	Long	Lt.	1												
			2												
		Hvy.	1												
			2												
	Short	Lt.	1												
			2												
		Hvy.	1												
			2												

Figure 4. Experimental Design: Matrix of Experimental Variables

3. Running Sequence and Statistical Design

Each of the subjects participated in 16 experimental sessions, each session representing all (12) possible combinations of target variables (columns in Figure 4), the different sessions defining all (16) possible combinations of weapon configuration and human performance variables (rows in Figure 4) as defined above. Each subject, then, was run through a total of 192 unique trial conditions. This design and procedure was compatible with an eight-way classification analysis of variance design (mixed model, subjects the random factor), repeat measures on seven factors, with 127 testable variance components. Subjects served as their own controls by running through all experimental conditions, thus eliminating individual differences as a factor in the error variance. To minimize any possibility that transfer effects might confound the results, order of presentation of target conditions was randomized for each experimental session, and the order of weapon and human performance variable combinations (experimental sessions) were randomized for each subject.

IV. EQUIPMENT AND FACILITIES

A. General

The secondary objective of the project is the design and fabrication of a system of equipment which will not only meet the needs of this study, but also the needs of possible second and third generation studies. Generally speaking, the characteristics of equipment systems for any experimental study are usually determined by the study objective and the requirements of the experimental design. While this is true, in general, for the present study, certain limitations of our laboratory facilities have constrained our approach to the development of the equipment system ultimately used in this study. These limitations and their impact are among those topics discussed in this chapter. Because of the complexity of the equipment system employed in this study, it is considered desirable to devote an entire chapter to the topic. The chapter discusses in some detail the following areas:

- Requirements of the equipment system
- Design constraints related to the geometry of the laboratory
- Design and function of the equipment system and subsystems

B. Requirements of the Equipment System

The first requirement of equipment for an experiment is to provide a capability to generate and/or measure the various independent and dependent variables of interest to the investigators. The independent variables for the present study were presented in Table 1, and include several levels of trigger slack, trigger pull, grip angle, target range, target motion and target exposure time. The system must provide these and also be capable of providing accurate and reliable data on the dependent variables (performance measures) of interest (see Chapter III, C). These measures of performance require the capability of measuring to the nearest one-half mil where the test weapon was pointed at intervals of 0.2 seconds throughout the trial. Also, the system must be capable of measuring the time of each trigger pull during the trial to the nearest one-tenth second. Finally, the system must be capable of distinguishing "hits" from "misses."

In addition to the above-mentioned capabilities, the equipment system for this study should possess, to some degree, the following characteristics:

- The test weapon (PDW) should physically resemble a real weapon in terms of size, weight, balance, operating characteristics and configuration.
- The system should be capable of producing test situations that resemble those conditions that could occur in close combat.

Regarding realistic test situations, for example, targets should appear at different places in the field of view and moving targets should move at speeds one might expect from real targets. Also, target exposure time should be relatively short as in the case of the real situation. Further, the equipment should be designed such that test subjects receive no feedback as to their aim error, a condition that prevails in close combat except when a hit is scored.

Two factors affected the nature of the equipment system developed for this project. First, the design specified that the test weapon (PDW) could not fire a projectile, and that recoil and noise would be treated as controlled variables, and their levels minimized across all levels of experimental variables. A second factor was the physical dimensions of the laboratory space available for the experiments. The laboratory room, measuring 16 feet by 20 feet, was the largest available space for the experiments, and that factor combined with the requirements for moving targets at ranges varying from 10 to 40 meters had to be considered in choosing from among alternative design approaches. These factors led to a number of design features in our system to guarantee a level of precision in measurement appropriate to this type of research.

C. Design and Function of Equipment

1. General

This section provides an overview of the equipment and materials used in the conduct of the experiments. The detailed characteristics of the equipment are provided in Appendix 1. For convenience of presentation, the equipment has been classified into the following six subsystems.

- PDW test weapon subsystem
- Stimulus presentation subsystem
- Data recording subsystem
- Control unit subsystem
- Data reduction subsystem
- Ancillary equipment and materials

2. PDW Test Weapon Subsystem

The test weapon was designed and fabricated by Bellmore-Johnson Tool Company, Hamden, Connecticut. The design was such that a total of eight different configurations could be obtained through the use of interchangable components. Common to all configurations was the slide which contained the sight system and the barrel and lens assembly. Two frames and four trigger assemblies complete the hardware necessary to obtain the eight different configurations (see Table 1). To the casual observer the primary difference in the configurations lies in the two different grip angles of the frames. The frame with the moderate grip angle (17.5°) is the frame of a Caliber .45 M1911A1. The second frame is also from a Caliber .45 M1911A1 but has been modified to have an extreme grip angle of 30°. The latter simulates the grip angle of a Luger pistol. Figures 5, 6, 7, and 8 show both the right and left side views of the two grip angle configurations. From the photographs it is evident that the configurations closely resemble the Caliber .45 M1911A1. The weight and center of gravity of both configurations (moderate grip angle and extreme grip angle) closely resemble the M1911A1. The test weapon fires a continuous beam of IR light and produces no recoil or report. The light beam is focused to a diameter of 0.08 inches at the screen. When photographed with IR sensitive movie film the light beam appears as either a round spot or a trace depending upon the amount of weapon movement at the instant of recording. When the trigger is pulled the time of firing is recorded by a timer/printer and at the same time an amplifier emits a "pop" as a signal to the shooter that he has "fired." This "pop," a short burst of static, is easily detectable but in no way approaches the loudness of a weapon report. The design does not limit the number of rounds fired during a test trial.

3. Stimulus Presentation Subsystem

Stimuli, or targets, are presented by projecting them on a curved

Figure 5. Right Side of PDW with Moderate Grip Angle

Figure 6. Left Side of PDW with Moderate Grip Angle

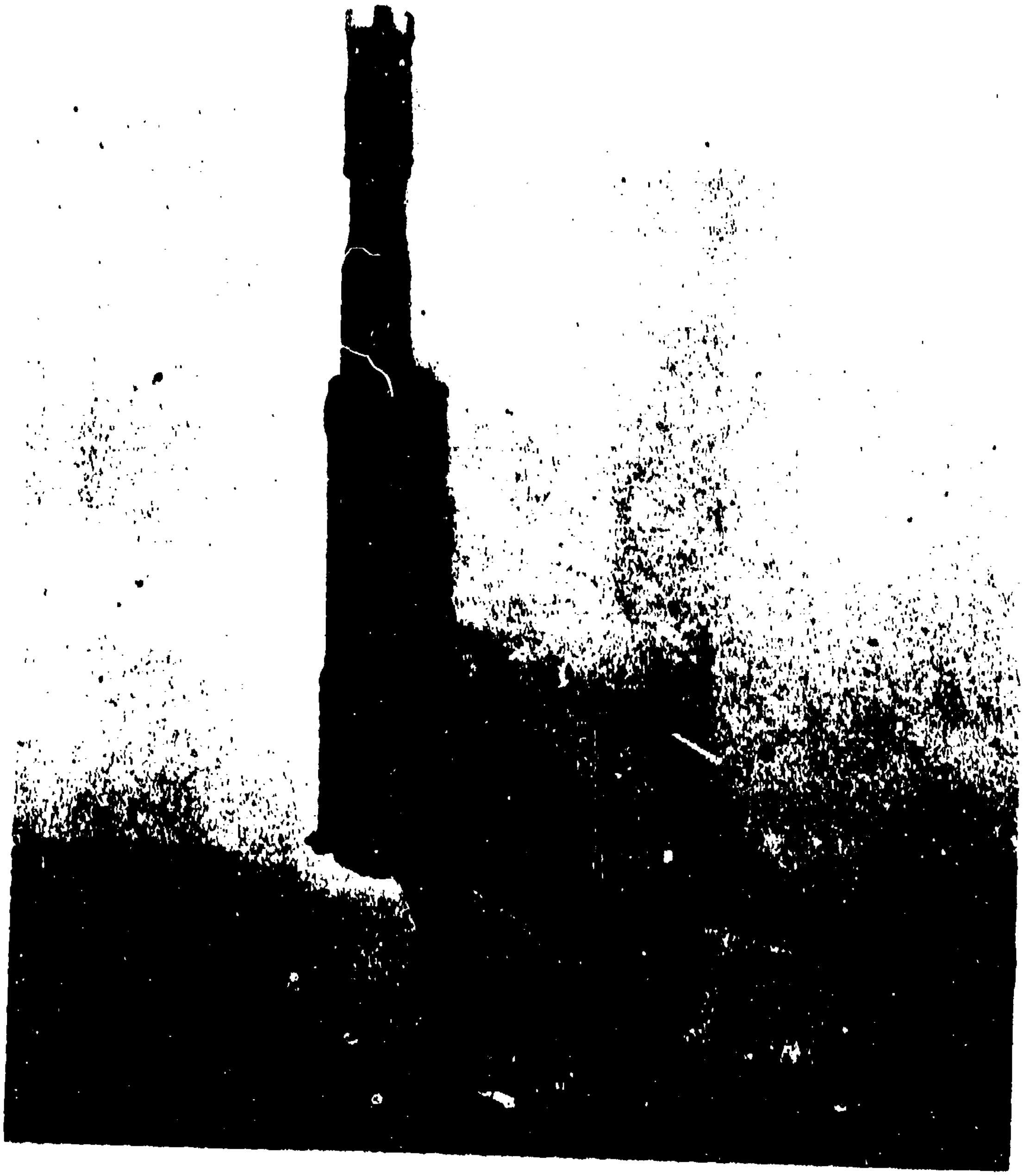

Figure 7. Right Side of PDW with Extreme Grip Angle

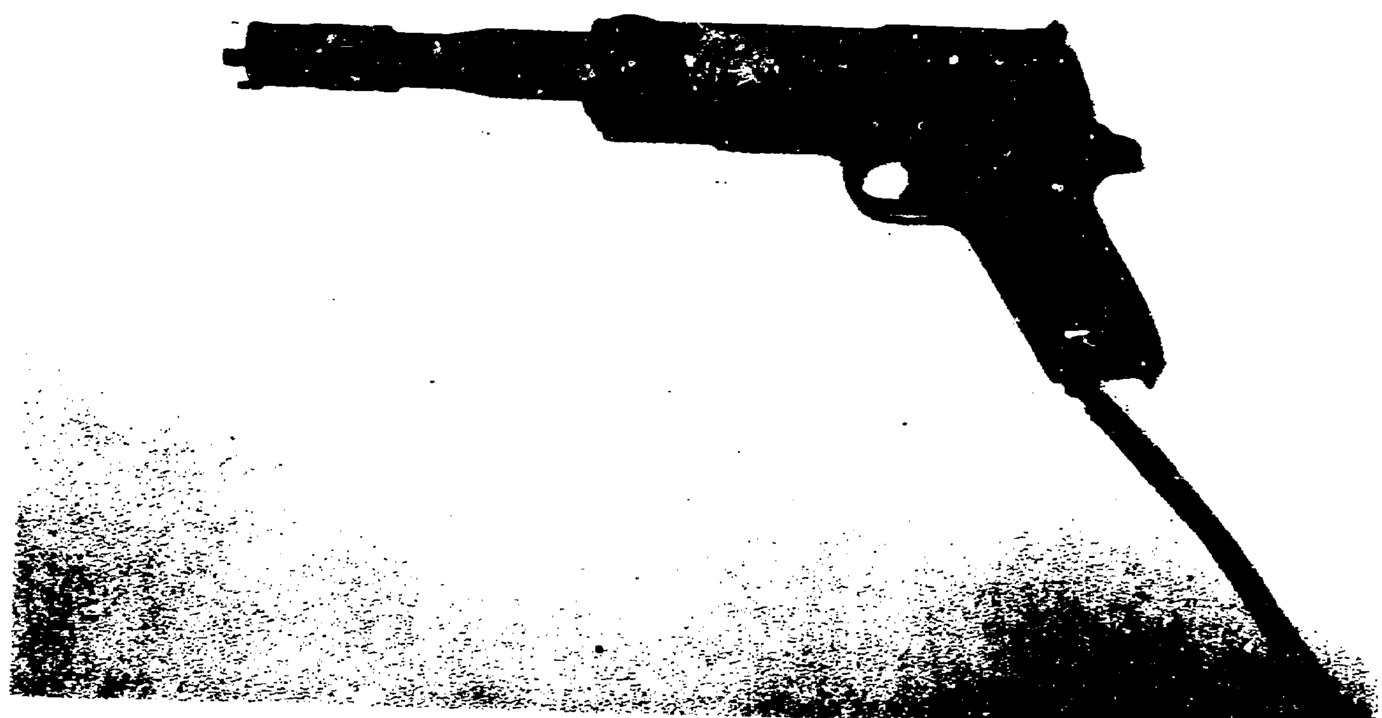

Figure 8. Left Side of PDW with Extreme Grip Angle

screen with a slide projector. Target movement is obtained by mounting the slide projector on a motor driven turntable (see Figure 9). Three different target slides were used to simulate target ranges of 10, 25, and 40 meters. The shape of the targets is shown in Figure 10 (background). A Control Unit (described below) controls the various stimulus presentation functions such as target exposure time, speeds of moving targets, etc. There is also a "Shooting Table" on which is mounted a pair of "Bar Light" projectors (see Figure 10). The primary function of the Shooting Table is to hide the slide projector and turntable position from the view of the test subjects to prevent them from receiving any cues as to the nature of the trial they are about to perform. The "Bar Light" projectors are used only during trials in which there is a moving target. Their only function is to project a vertical bar of light approximately 3/4 inches wide and 30 inches high at the screen. The bar of light indicates to the subject the terminal position of the moving target. When the leading edge of the moving target touches the bar of light, the target and bar of light are extinguished. Thus, the bar of light simulates a point of cover to which the target is "running."

4. Data Recording Subsystem

Data recording is accomplished through the means of a movie camera with IR sensitive film and a timer/printer to record the time of each trigger pull. The movie camera is mounted on the Turntable beside the slide projector (see Figure 9) and aimed to photograph the area of the screen covered by the slide projector. The relationship of the camera and slide projector remains constant throughout all conditions. The timer/printer is located on the Experimenter's Control Desk and is shown in Figure 11.

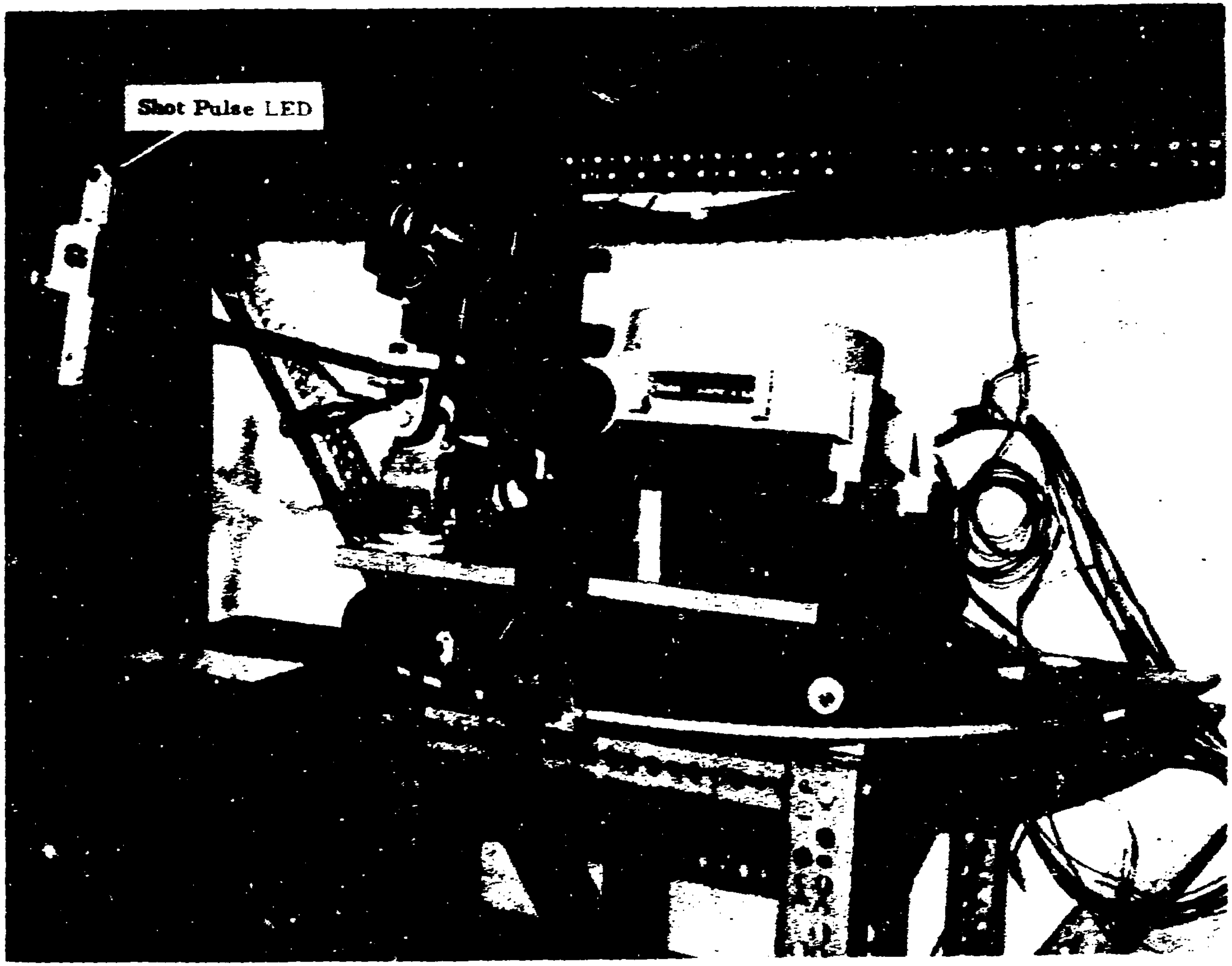

Figure 9. Detail View of Turntable with Camera and Projector

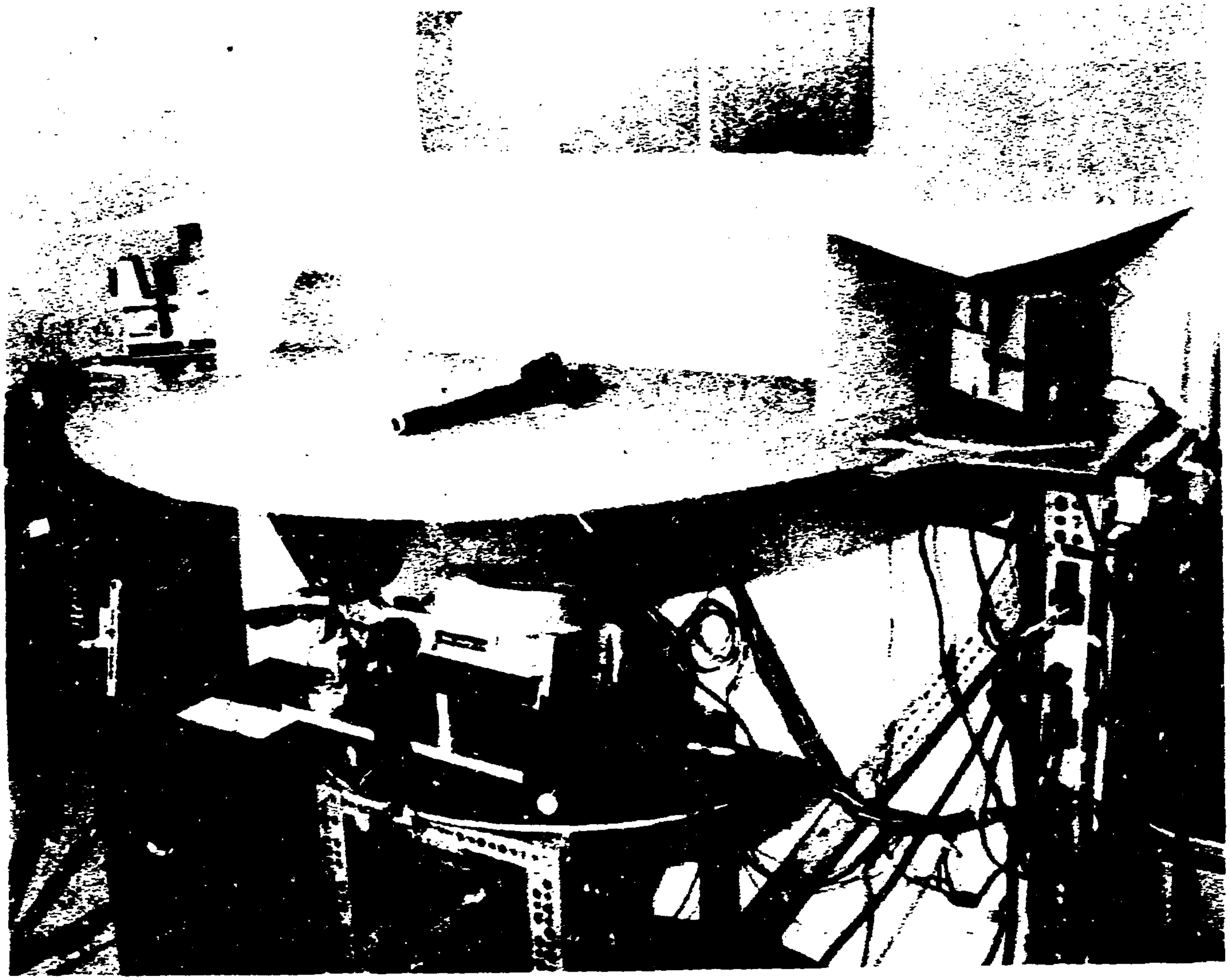

Figure 10. General View of Shooting Table with Bar Light Projectors

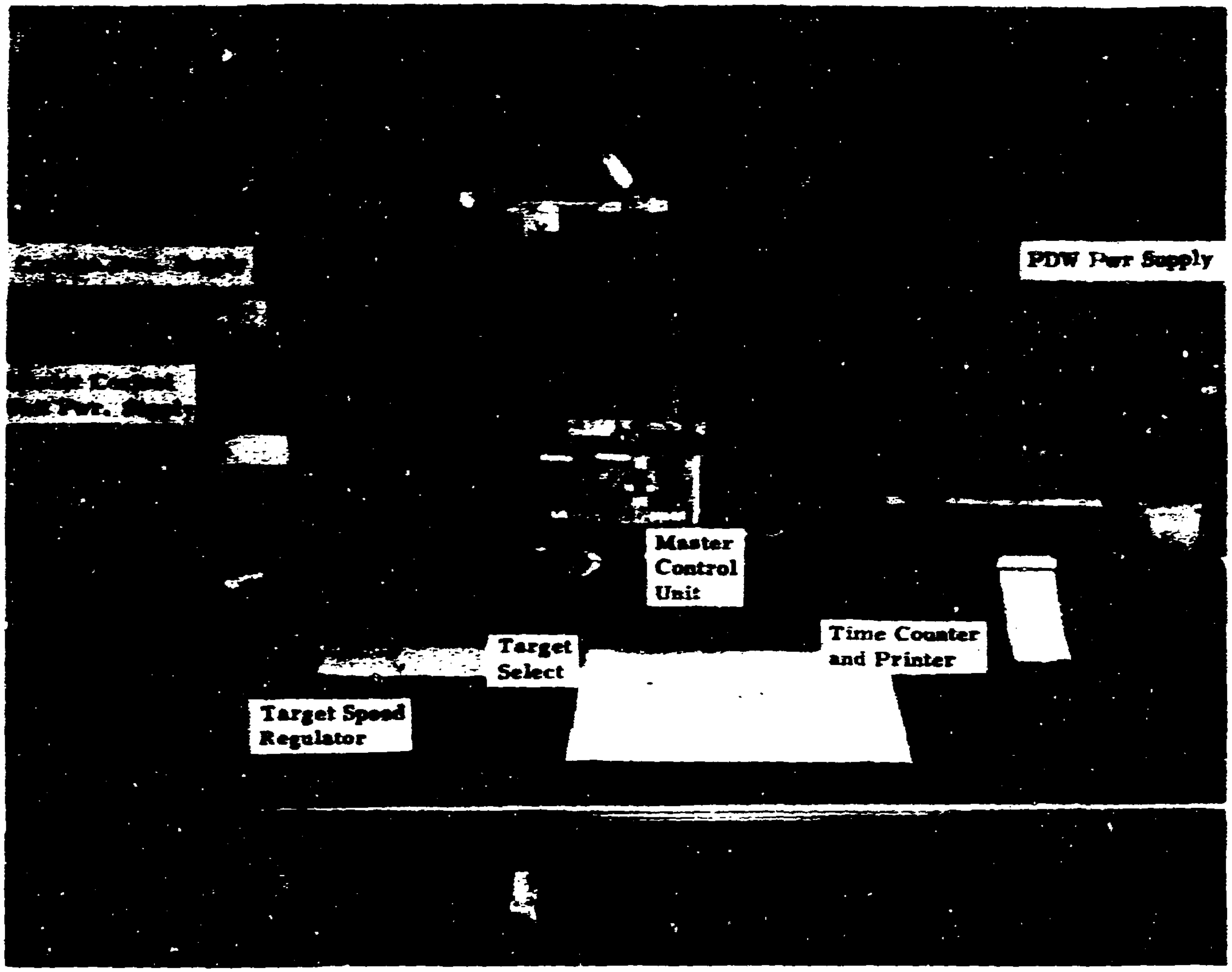

Figure 11. Experimenter's Control Desk

To aid in correlating the timer/printer records with the film record, a "Shot Pulse" LED was utilized. From Figure 9, it can be seen that the LED is mounted on a boom in front of the camera and in the camera's field of view. The LED looks at the camera and, when the trigger is pulled, emits IR light for a period of 0.04 seconds. This produces a large black "Cannonball" (shot pulse) in the lower right corner of the film frame in which the trigger was pulled. Figure 12 shows the nature and location of the cannonball (shot pulse) as it appears to the film analyst.

5. Control Unit Subsystem

The overall control of test trials, including presentation of stimuli and data recording, is accomplished through three items of equipment located on the Experimenter's Control Desk. These items are the Master Control Unit, the Target Speed Regulator and the Target Selector (see Figure 11).

The Target Selector is simply a remote control unit for the slide projector and its carousel and permits the remote selection of the desired target slide. The Target Speed Regulator controls the motor that drives the Turntable. Because we are simulating three target ranges on the screen, three different speeds are necessary, one for each target range.

The Master Control Unit has the following functions or capabilities:

- Master Control Unit - power ON/OFF
- Turntable position - starting position of the target on the screen
- Target exposure time - length of trial (2-4 secs)
- Target movement - moving or stationary
- Direction of target movement - right or left

- **Start trial**
- **Reset**

6. Data Reduction Subsystem

The raw data collected during the experiment were recorded on 16 mm movie film, and the paper tape produced by the timer/printer. These data had to be correlated, reduced and somehow arranged in a manageable form for statistical analysis. By employing a 16 mm film analysis projector and a "sonic digitizer" (supplied by U.S. Army HEL), the aiming and shot data from the movie film were translated into numerical coordinates (by the digitizer) which were recorded simultaneously via teletypewriter on printout paper and punched paper tape. Data from the timer/printer were manually correlated with shot coordinates and inserted on the punched paper tape by means of the teletypewriter. The raw data now on the punched paper tape were ready for final reduction and statistical analysis by a computer. Final reduction involved the definitions of the dependent variables used in the analyses which are discussed in Chapter VI, B.1.

A team of two analysts was required to operate the equipment and reduce the data. One analyst sat at the digitizer screen and, with a digitizer stylus, input X Y coordinate data to the digitizer's teletypewriter. Figure 12 (posed) shows an analyst working at the digitizer screen. Note that in Figure 12 one can see the images of both a large target and a shot pulse signal from the Shot Pulse LED. The image contrast in Figure 12 is much poorer than the actual contrast obtained during analysis. The other analyst (see Figure 13 - Posed) controlled the projector with a remote control unit, and with the teletypewriter manually entered identification and time data into the punched paper tape.

7. Ancillary Equipment and Materials

During the conduct of the experiments, several functions had to

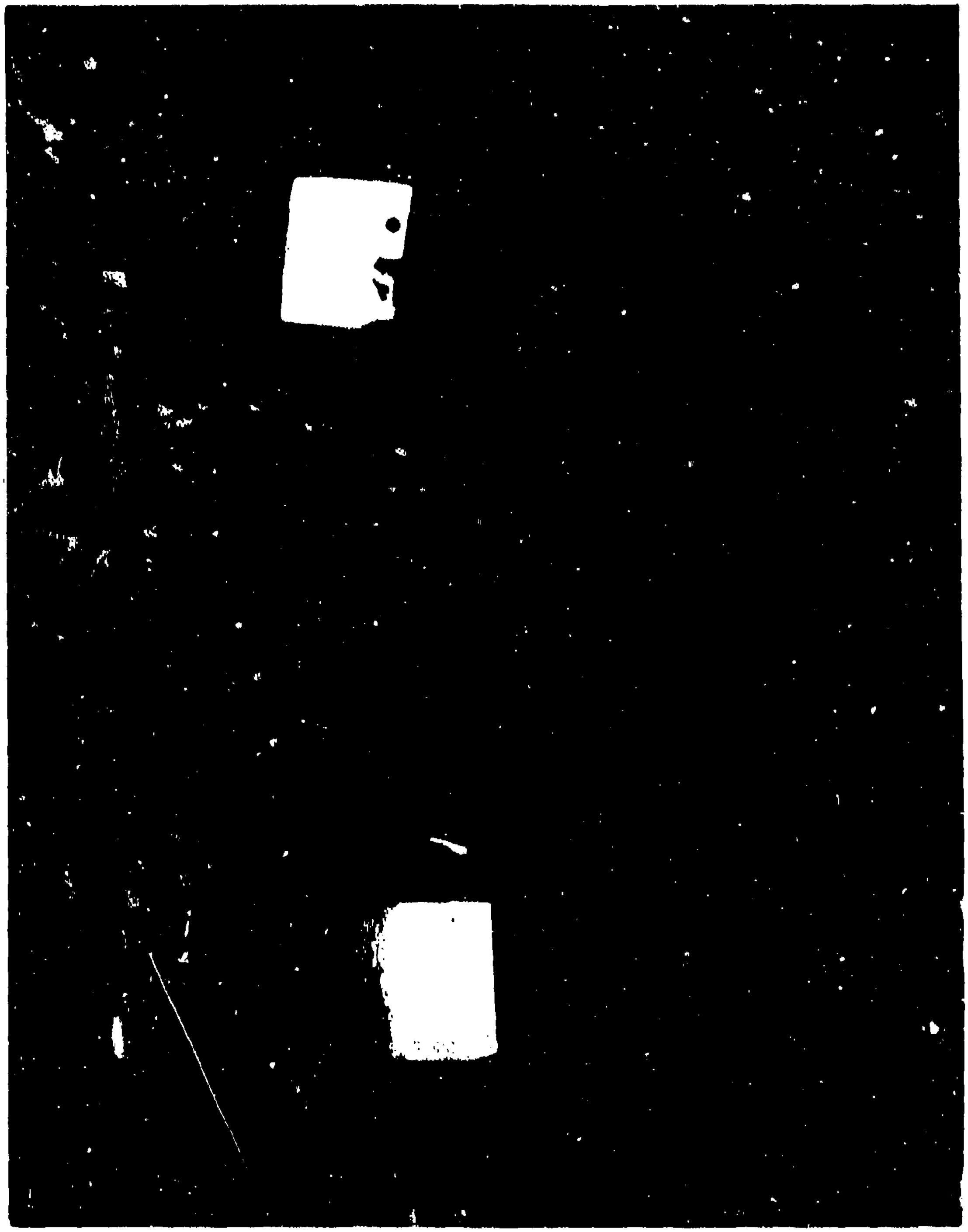

Figure 12. Analysis Room - View of Digitizer

Figure 13. Analysis Room - View of Projector and Teletypewriter

be performed requiring the use of some equipment and materials that don't readily fit the equipment categories described above. These functions and associated materials are described here.

Trial Identification. A system of 45 Identification Slides was developed to distinguish between test trials and test sessions recorded on film. With these slides each test trial could be associated with the subject who performed the trial. Before beginning a trial, appropriate ID slides were displayed on the screen and photographed with the movie camera.

Visual Choice Reaction Time Apparatus. As part of the screening of subjects, candidates had to perform visual choice RT tasks. Figure 14 shows the equipment used for screening subjects. The apparatus functions as follows: when the experimenter depresses one button on the stimulus select unit, a small light on the response unit opposite the corresponding button is illuminated. Simultaneously, the timer starts. The subject's task is to extinguish the light as rapidly as possible by depressing the button associated spatially with the light. When the correct button is depressed, the timer stops.

Weapon Calibration (Sights). Prior to each period of testing the zero of the test weapon was checked and, when necessary, the sights were adjusted appropriately. The equipment required included a heavy duty surveyor's tripod with a bench rest mounted on it, a calibration target and of course the test weapon itself. Calibration was necessary because the arc in the zirconium arc lamp tends to drift about on its filament as the lamp approaches the end of its expected life. In general, the arc is fairly stable and only occasional adjustment of the sights was required.

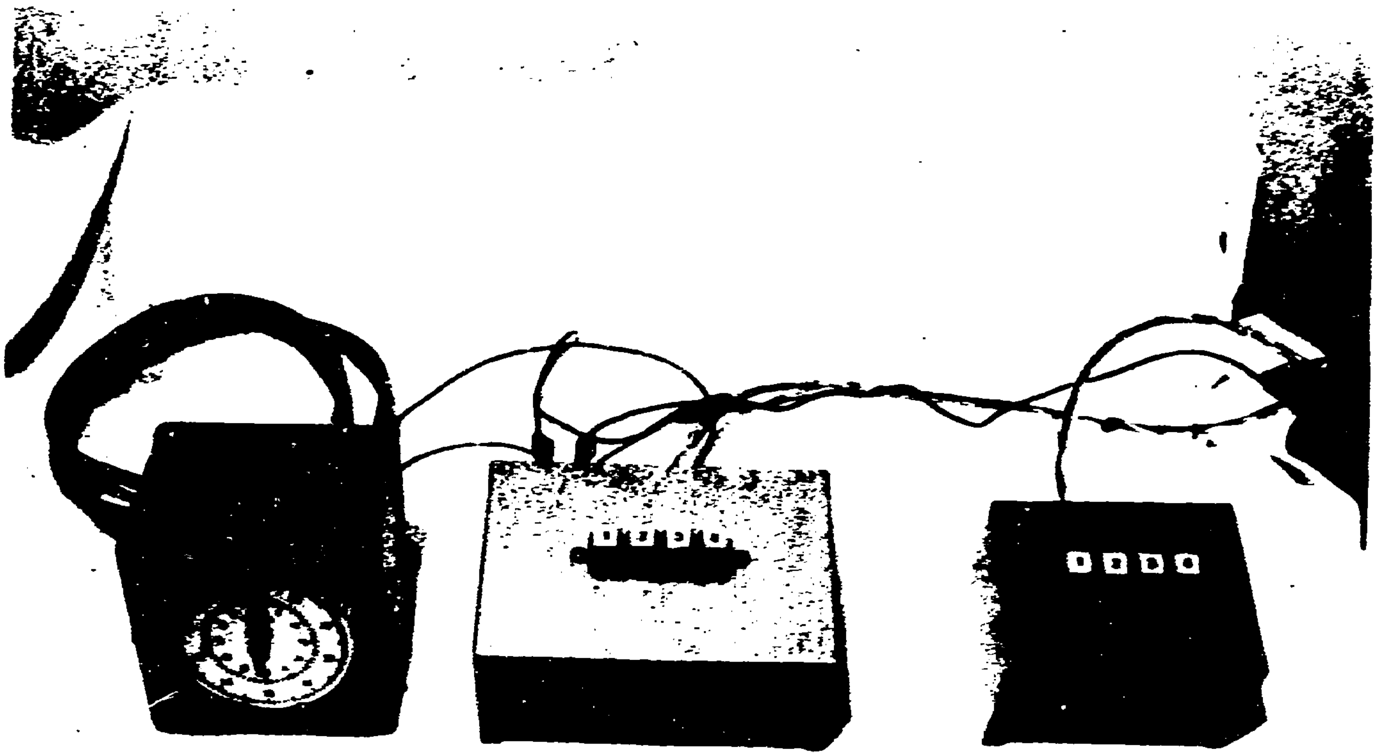

Figure 14. Visual Choice Reaction Time Apparatus

Muzzle Calibration. This was carried out immediately prior to every test trial. The materials and equipment used in this procedure included a 35mm camera mounted on a tripod, the position of which was fixed, and a muzzle calibration chart mounted on the wall opposite the camera. The procedure employed to establish muzzle calibration is described in Chapter V. However, since this function is part of every test trial it is felt that the rationale for it should be discussed at this point.

Rationale for Muzzle Calibration. The requirements for precision of measurement in this study, combined with the relatively short absolute distance between the test weapon and the screen, made it necessary to control the spatial location of the weapon's muzzle during all test trials. Measurements of shot group dispersion are affected when the distance between the muzzle and screen changes. This relationship is shown in Figure 15.

The figure shows three muzzle positions, in the same horizontal plane, each at different ranges from a screen. From each muzzle position an angle of dispersion is drawn to intersect the plane of the screen. The angles are of equal size. The impact of range on dispersion is clearly shown by the "circles" on the screen. Since we are interested in measures of dispersion in this study, it was important to control this potential source of measurement error. At ranges beyond 15 to 20 feet small differences of a few inches in range have no significant effect on measures of dispersion. However, in this study the absolute muzzle/screen distance was in the neighborhood of 8 to 9 feet. Assuming that a 5% error in measurement is acceptable, and assuming a range of 8 feet, the range from the muzzle to the screen cannot vary more than 4.8 inches. This means that a subject, during a test trial and from trial to trial, must maintain a fairly constant muzzle/screen distance. Because, in this

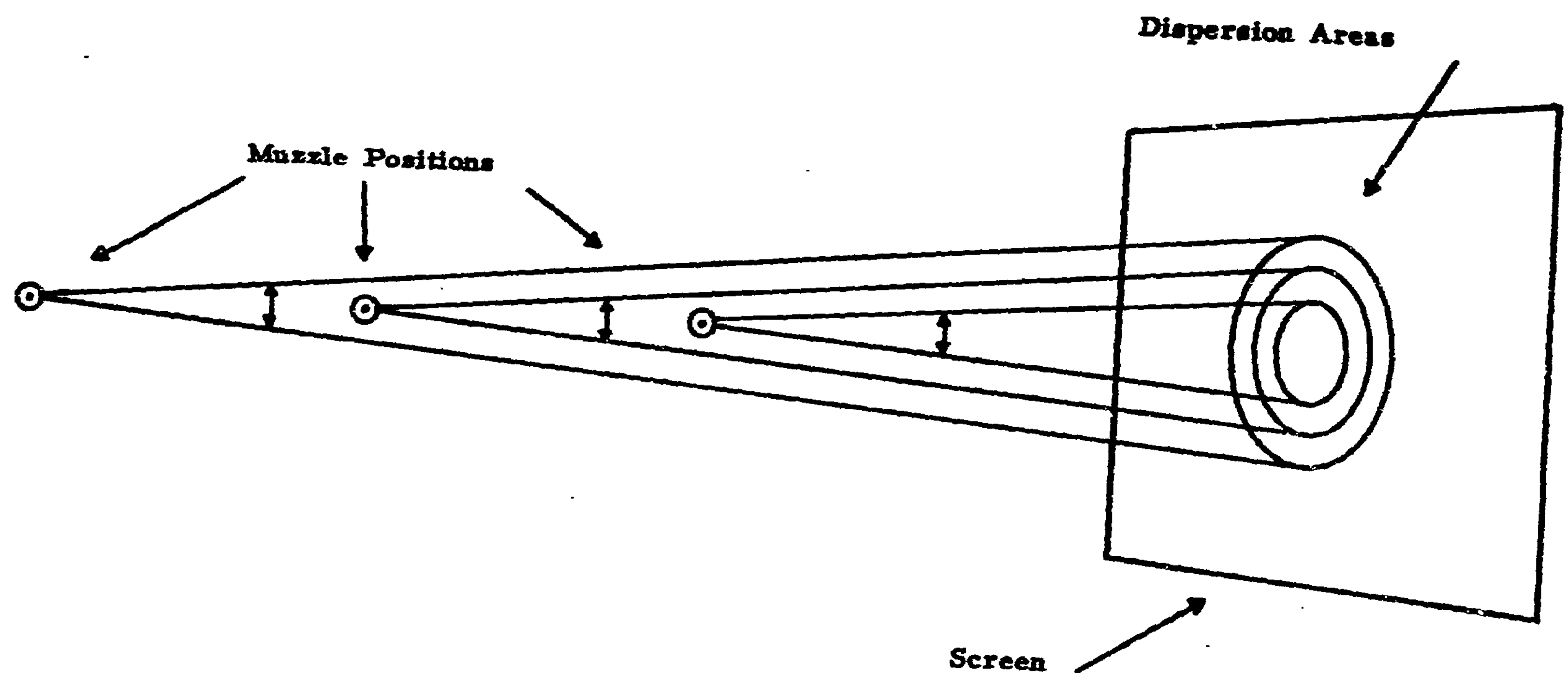

Figure 15. The Rationale for Muzzle Calibration

experiment, each subject was his own control, it was not necessary for all subjects to position the weapon within the same 4.8 inch envelope. However, it was necessary that an envelope be established for each subject and maintained from trial to trial.

Actually, two envelopes were established for each subject, one for each shooting stance--1-hand hold and 2-hand hold. Of course, if one compares a subject's performance across shooting stances, it is necessary to apply a correction factor to account for the difference between the two muzzle/screen envelopes.

D. Laboratory Facilities

1. General

The dimensions of the laboratory are 16 feet by 20 feet. The laboratory was large enough to comfortably house all necessary equipment and, at the same time, conduct the experiments. The arrangement of the equipment in the laboratory is shown in Figure 16. Figure 17 shows the geometry of the laboratory and several of its critical dimensions. The room was illuminated by four standard fluorescent light fixtures and was equipped with a standard dimmer switch. To enhance target contrast, the tests were conducted under the lowest level of ambient light permitted by the dimmer switch. It should be noted, however, that the light level in the room during tests was sufficient for reading a newspaper.

2. Laboratory Constraints

While the size of the laboratory was sufficient for conduct of the study with the target ranges actually employed, its dimensions did, in fact, impose practical limitations on the target ranges that might be

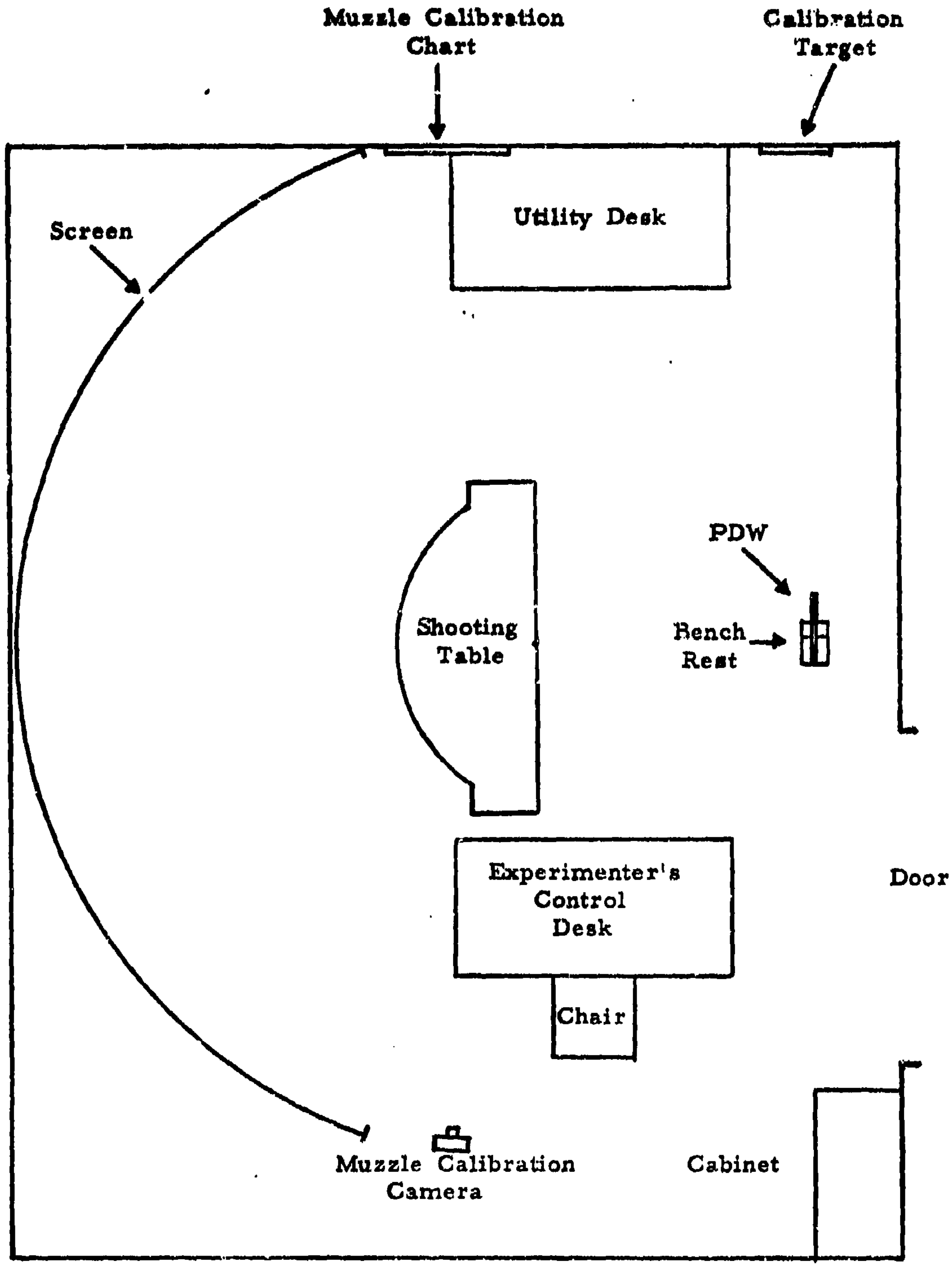

Figure 16. Floor Plan of Laboratory (Schematic)

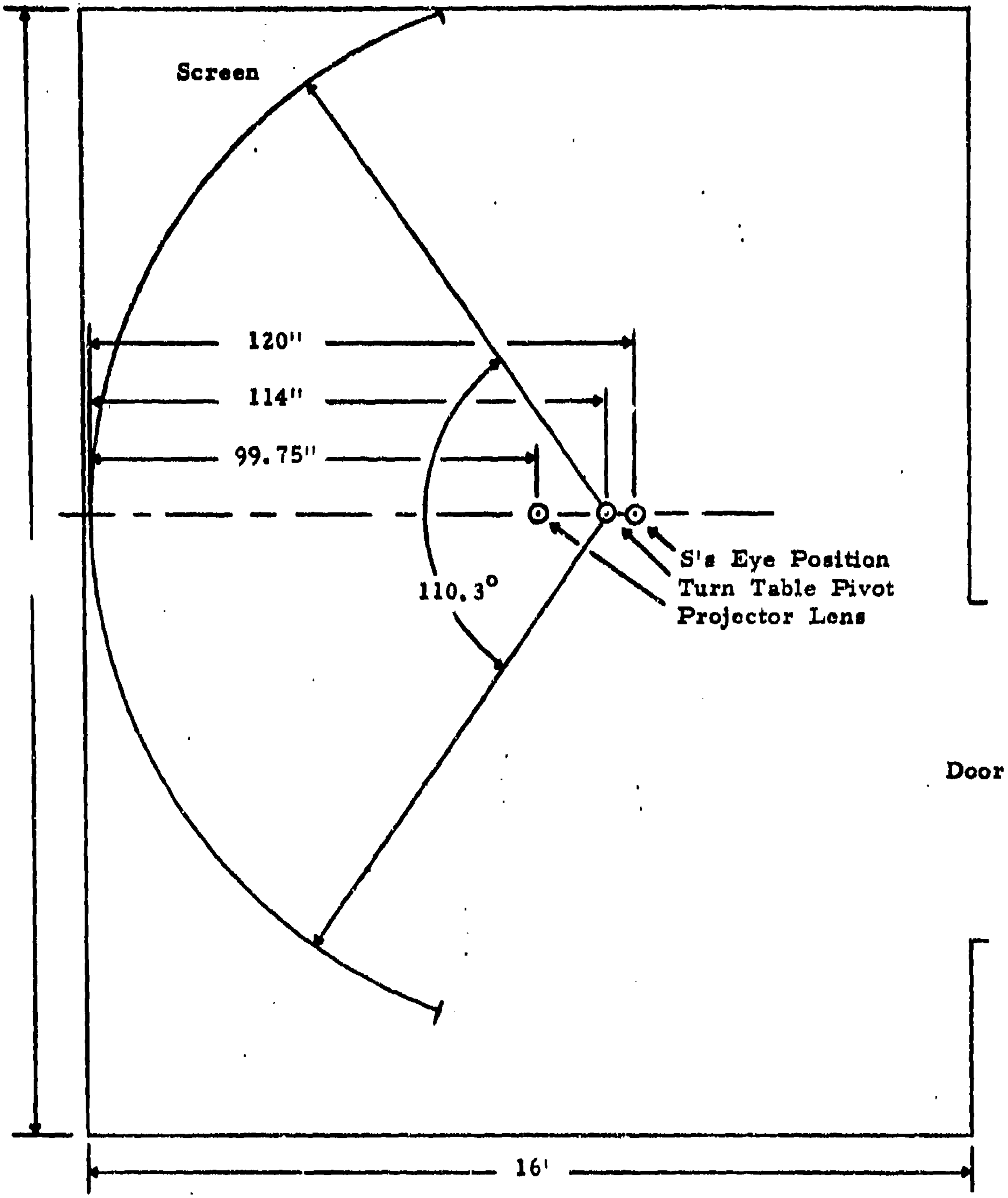

Figure 17. Geometry of the Laboratory

simulated. Available floor space limited the maximum practical subject-to-screen distance to about 10 feet. This in turn limited the distance from the turntable axis to the screen to a maximum of 9.5 feet. Figure 17 shows that a 4 second, 10 meter target moving at a simulated rate of 15 feet per second on a screen with a radius of 9.5 feet would define an arc of 110.3 degrees. Originally it had been planed to simulate a target range as close as 5 meters. A 4 second moving target at this distance, however, would require an arc in excess of 220°, exceeding available floor space, and requiring the subject to complete nearly two-thirds of a revolution in following the target from onset to completion of the trial.

The 10 foot limitation in subject-to-screen distance magnified another problem in the geometric design of our floor plan. Referring to Figure 17, it should be noted that the projector lens rotates around the turntable pivot point which, in turn, coincides with the center of curvature of the screen. Thus, the size of the target image at the screen remains constant from point-to-point on the screen. The problem described below would not exist if the location of the subject was also coincident with the pivot point of the turntable.

Figure 18 is a schematic representation of the geometry of this problem. Point A is the center of the screen. Point D is the extreme right position of the target on the screen. Point B is both the pivot point of the projector and the center of curvature of the screen. Point C is the location of the subject. The dotted arc represents an arc of a circle with a radius the length of line A-C with the center at Point C. The problem is manifest, in Figure 18, when the projector is rotated so that the target appears at Point D. Physically the target at Point D is the same size as it was at Point A because AB equals BD. However, because AC is greater than CD, the target image looms closer to the subject at point D than at Point A, subtending a greater angle in his visual field and shortening weapon-to-target distance.

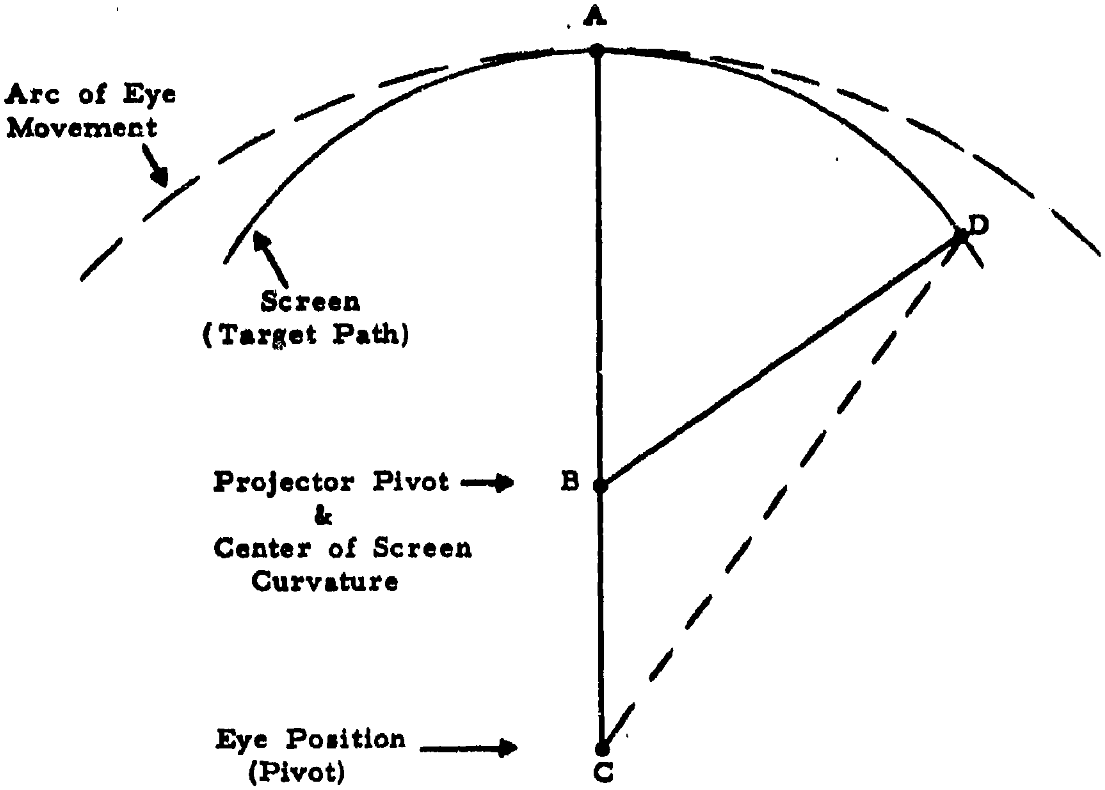

Figure 18. Geometry of Target Distance Variation Problem (Schematic)

Since our experimental design did not call for apparent (subjective) variations in target distance during the course of a trial, and since it was necessary to minimize variations in weapon to screen distance (for reasons discussed earlier with regard to muzzle calibration) it was clearly in the interest of this study to keep the length of line CD (Figure 18) as close as possible to that of AC. This was accomplished by placing the pivot point of the projector (point B) as close as possible to the subject's position (point C), a distance (segment BC) of only 6 inches. As a result, the most extreme variation in subject-to-target distance (CD) was only 1.6 inches (118.4 inches as compared with 120 inches at the center of the screen). This variation yielded no detectable distortion in apparent target size and was well within acceptable limits ($\pm$ 4.8 inches) for variation in weapon-to-screen distance.

V. PROCEDURES

A. General

The objective of this chapter is to outline the nature of the more pertinent procedures employed during the conduct of the tests. Further recording forms, protocol sheets, and verbatim instructions, etc., are contained in supporting appendices. The chapter is divided into three major sections as follows:

- Pretest Procedures
- Test Procedures
- Data Reduction Procedures

Pretest procedures are concerned primarily with subject recruiting, screening, orientation and training. The test procedures section deals with the activities of the experimenters and are concerned with the procedures involved in the actual test and data collection. These activities include equipment setup, instructions to subjects and equipment operating procedures. The section on data reduction procedures is concerned with the activities of the team of analysts and the tasks they performed for analyzing the raw data.

B. Pretest Procedures

1. Subject Recruiting

The recruiting process was conducted on an informal basis through telephone contact with Stamford's Committee on Training and Employment, Inc. (CTE), volunteer fire departments and high school and college students known to the experimenters. During the first telephone contact, candidate subjects were given a general description of the experiment and the task they were expected to perform. The candidates were also told how much of their time would be involved and that they would receive a stipend of $50 for their performance. Appointments were set up for interested candidates for screening and training sessions.

2. Screening

Appendix 2 is a detailed outline of the screening and orientation procedures followed with every subject. This outline was prepared prior to the recruiting of subjects and was used as a script for each of the screening and orientation sessions. Screening sessions and subsequent training sessions were conducted with groups of two to four candidates. We found it much easier and less time-consuming to work with groups of two candidates than with three or four candidates. The first step in screening was to test the vision of candidates by means of a Snellen Eye Chart. Subjects whose vision was 20/40 or better were accepted and permitted to proceed to the next step in screening. Two candidates failed to meet the visual acuity standard and were dismissed. The next step in screening involved adequate performance on a visual choice reaction time task. Norms were estimated from a group (N=54) of college undergraduates performing on a similar task under similar conditions.* All of our remaining candidates obtained mean RT's placing them above the 5th percentile (our cutoff criterion) as determined from these norms. The apparatus for this task was described in Chapter IV, while test instructions appear in Appendix 3.

3. Personal Data Form

Those candidates who passed the vision and the perceptual motor screening tasks were next asked to complete a personal data form, a copy of which is in Appendix 4. This form contained information pertaining to the subject's name, age, race, years of education, and visual acuity.

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*Unpublished data collected by L. Lowden, 1970-71.

Following completion of the personal data, physical measurements were obtained on the subject's height, weight and hand length and breadth. This information was also recorded on the personal data form.

4. Orientation

During orientation, subjects were briefed as to the background of the problem and the purposes and objectives of the study. Following this, the subjects were familiarized with the equipment and were shown a demonstration of what a 2 second, 10 meter moving target looked like. Finally, the subjects were shown a short strip of test film which depicted what the data they were to produce would look like. Appendix 2 contains the detailed outline of the orientation program.

5. Training Program

The complete outline of the training program given subjects is contained in Appendix 5. The content of this program closely followed the marksmanship training program specified in the Department of the Army Field Manual FM 23-35. Certain portions of the program in the FM 23-35 were omitted as they were inappropriate in a laboratory context. Also, the duration of the subject's training was only two hours, although, each subject received intensive personal instruction during that period. The subjects were taught the proper sight picture, shooting positions and trigger squeeze and were given practice in each exercise. The shooting positions taught were the 1-hand standing and the 2-hand standing positions. These positions are depicted in Figures 19 and 20, respectively. The 1-hand shooting stance was identical to that specified in FM 23-35, however, the 2-hand shooting stance is that recommended by law enforcement agencies.

Muzzle Calibration Procedures. After subjects had learned and practiced proper shooting positions, data was collected on each subject for the purpose of determining the location of his muzzle calibration

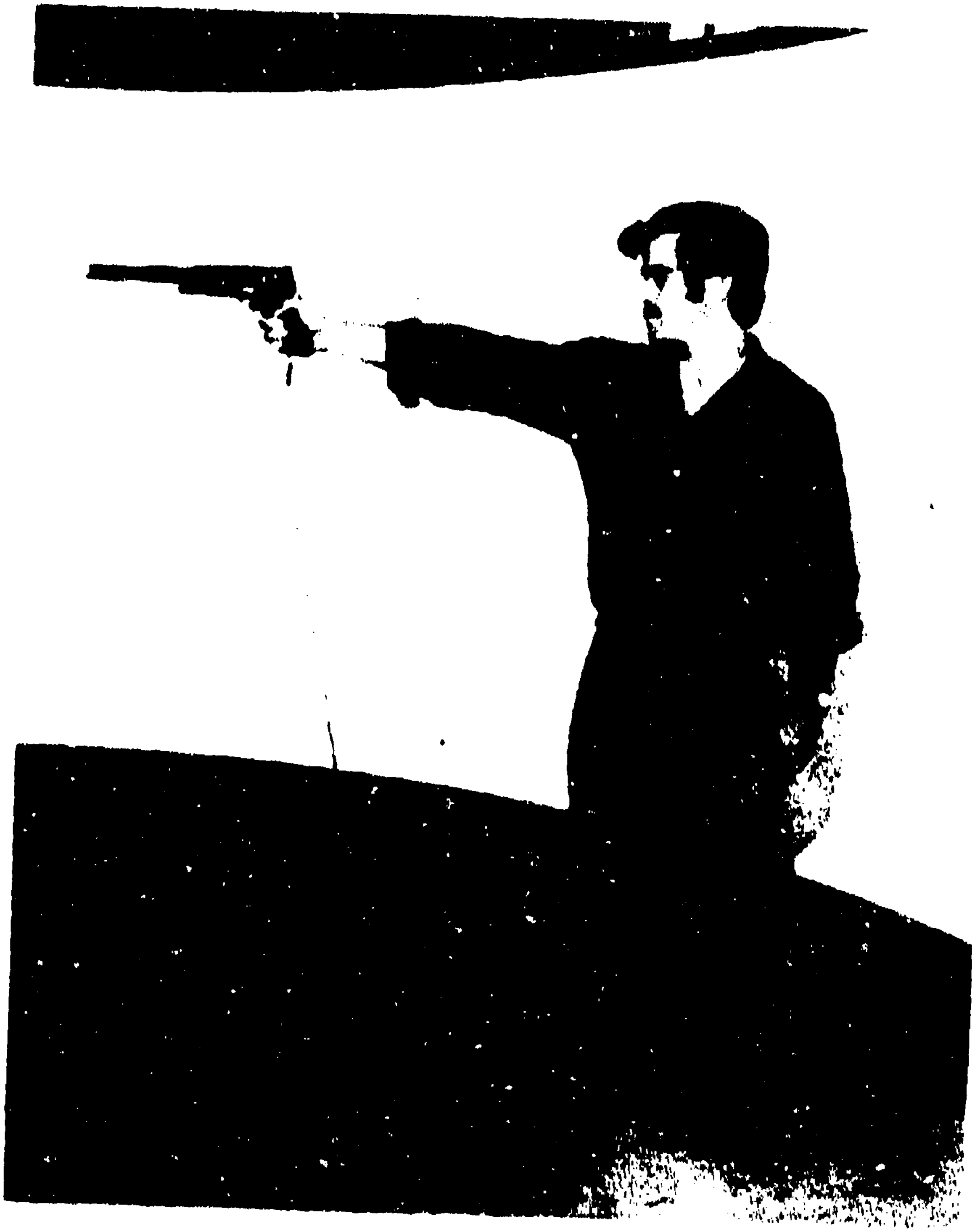

Figure 19. Subject Demonstrating One Hand Shooting Stance

Figure 20. Subject Demonstrating Two Hand Shooting Stance

envelope. The procedure involved determining for each subject in both of his shooting positions the average location, in space, of the weapon muzzle with respect to a fixed reference.

The geometry of the measurement situation is as follows:

- The muzzle calibration charts are mounted on the wall to the right of the shooting table (see Figure 16).
- The 35 mm camera mounted on a tripod is located to the left of the shooting table and near the left wall of the laboratory.
- The subject assumes a proper shooting stance at the shooting table.
- The relationship of the muzzle calibration charts and the camera is such that the muzzle of the test weapon is between them. Figure 21 shows this relationship as seen from the position of the camera. Figure 22 shows the experimenter demonstrating the use of the muzzle calibration camera. NOTE: A camera is not necessary; any sighting device that fixes the experimenter's eye in one position will suffice.

The procedure for obtaining the muzzle calibration data is as follows:

- The subject assumes a proper shooting stance at the shooting table.
- The experimenter, looking through the viewfinder of the camera, notes and records the muzzle position with respect to the calibration chart in the background.
- The subject then steps back from the shooting table--relaxes for a few seconds--and then resumes the same stance at the shooting table.
- This procedure is repeated until ten measures for each stance have been obtained.
- From these data the mean muzzle position is computed and recorded for each subject.

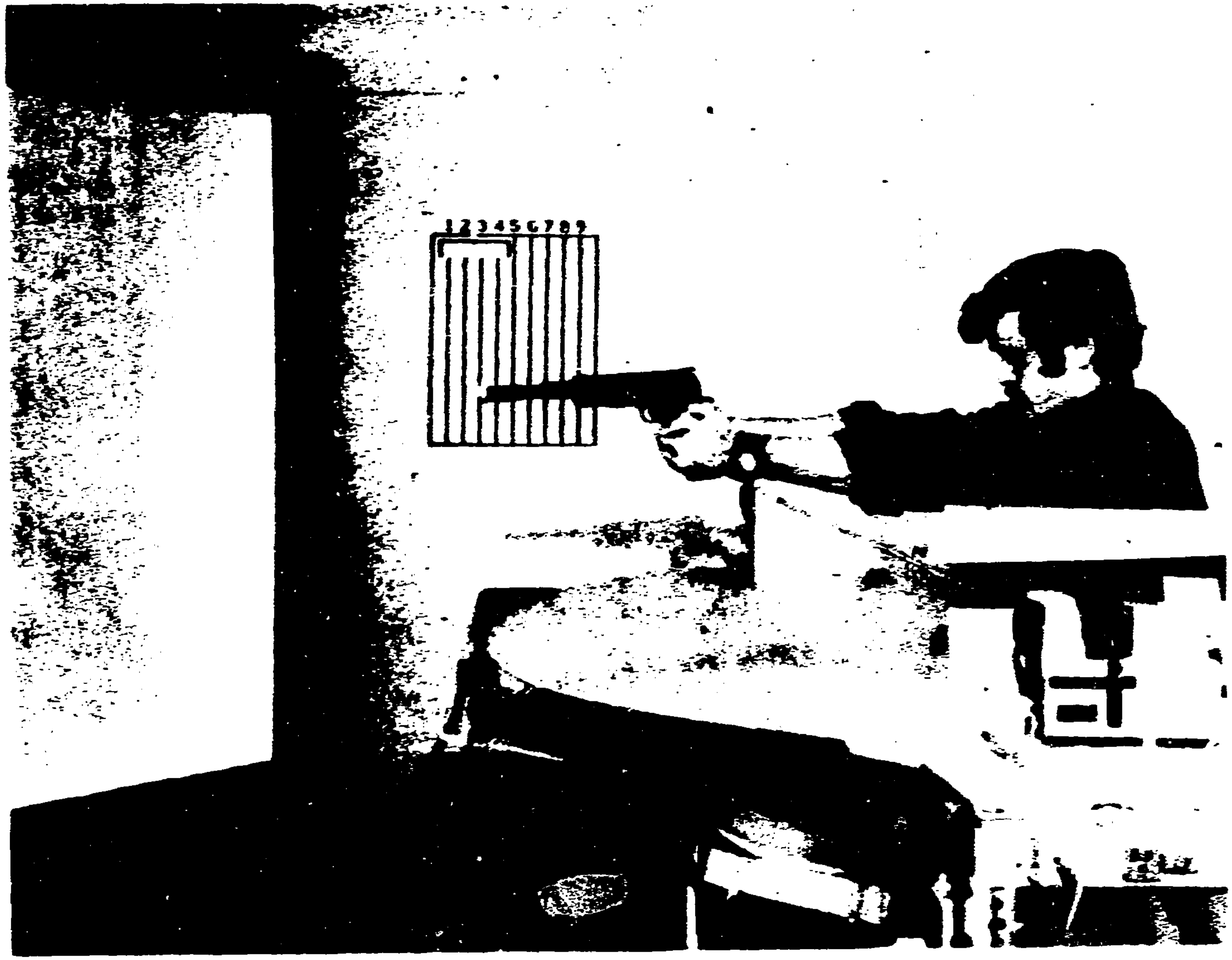

Figure 21. Subject Demonstrating Muzzle Calibration Procedure

Figure 22. Experimenter Demonstrating the Use of the Muzzle Calibration Camera

Practice Firing. Subjects were given the opportunity to familiarize themselves with the test weapon through a 96-round practice firing program. This practice firing program was modeled after the "familiarization" regime found in FM 23-35. Using a stationary target and a range of 25 meters, the subjects fired all eight weapon configurations using both the 1-hand stance and the 2-hand stance. For each weapon configuration and shooting stance, the subjects fired three rounds self-paced fire and three rounds rapid fire. Four partially random firing sequences of weapon/stance conditions were developed. To minimize order effects, each firing sequence was given to only four subjects. Appendix 6 contains copies of the four practice firing sequences. Instructions given to subjects for the practice firing program are contained in Appendix 7.

To provide the subjects with performance feedback, a scheme was devised such that the experimenter could see the light spot produced by the test weapon, while, at the same time, the subject was prevented from seeing the light spot. To accomplish this, a green filter was placed on the muzzle of the test weapon, and the subjects wore a pair of goggles equipped with a red filter. After each subject had fired each group of three rounds, the experimenter informed the subject of his performance in terms of hits and misses. Appendix 7 contains the instructions given to subjects for practice firing program.

C. Test Procedures

1. Test Program

The matrix of experimental variables presented in Figure 4 shows that there are 192 individual test conditions. These conditions were grouped into 16 sessions or sets of 12 trial conditions each (see Chapter II, E. 3.). Subjects were tested on two different days, each day consisting of eight sessions of 96 test trials. In most cases subjects completed their trials over a period of 2-3 calendar days.

2. Setup Procedures

Prior to beginning testing on any given day, the movie camera had to be loaded, mounted in position on the turntable and aligned so that its field of view coincided with that of the target slide projector. Next, all of the equipment were turned on and warmed up. Following a short warm-up period, the weapon "zero" was checked and when necessary the sights were calibrated. Because of small day-to-day fluctuations in the laboratory's line power, it was necessary to determine each day the appropriate settings on the Target Speed Regulator so that moving targets would traverse the screen at the proper rate.

3. Subject Briefing

When a subject reported for testing, the experimenter reviewed with him the nature of a correct sight picture, and with the use of practice targets showed the subject where the center of mass was located on each of the three targets. The subject was then required to demonstrate the proper shooting stance. Following this review, the subject was handed a small tape recorder on which his final instructions were recorded. Appendix 8 contains a verbatim transcript of the subject's instructions. Finally, before testing began, the subject was instructed that between trials he should step away from the shooting table and at the same time turn his back to the shooting table. This was done in order to reduce any cues that the between-trial activities of the experimenter might afford.

4. Trial Procedures

Two experimenters were required to run the test trials efficiently because of the many equipment setting changes that had to be made between trials. One experimenter (E_1) sat at the Control Desk and operated the equipment and the trial start switch. The second experimenter (E_2) was responsible for controlling the subject, trial IDs, setting bar lights in proper positions, making sure the turntable was in the proper starting position and checking the subject's muzzle calibration. To facilitate setting up task conditions between trials and minimizing the possibility of error, procedural checklists for sessions of 12 trials were developed for both experimenters. These checklists not only told the experimenters what to do, but provided space for each experimenter to check off each item as he accomplished the task. The randomization of trials made each set of checklists unique to each subject, thus, for each subject 16 sets of checklists were necessary to complete the subject's test regime. Appendix 9 contains samples of the E_1 and E_2 procedural checklists.

After the equipment was set up for a test trial, the subject was asked to step up to the shooting table and assume the proper shooting stance. To assist subjects in obtaining their proper shooting stance, foot positions were marked on the floor so as to assure that the subjects would stand in approximately the same place from trial to trial. Figure 23 shows a subject at the shooting table. As the subject stepped up to the table, E_2 reminded him of the essential features of the proper shooting stance. Appendix 10 gives statements used by the experimenter to remind the subject of the essential features of the shooting stance.

As the subject took his stance, he assumed a ready position, which is the same as the desired shooting stance except he is aiming his weapon at a point in the center of the screen about 2 feet above the floor. At this point E_2 asked the subject to raise his weapon to the firing position and checked the muzzle calibration. If the check was satisfactory, the subject was asked to resume the ready position and indicate when he was ready for the trial to begin. Shortly after the subject had indicated his readiness,

Figure 23. Subject at Shooting Table

E_1 activated the start button on the Master Control Unit, and the trial began. If, during the muzzle calibration check, the muzzle was outside of the 4 inch envelope, the subject was asked to take his stance again, and the procedure was repeated until the satisfactory muzzle calibration was obtained.

In practice it was found that subjects were surprisingly consistent from trial to trial in maintaining their proper muzzle calibration envelope. While no data were collected on the subject's inconsistency regarding the muzzle calibration check, it is estimated that less than 5 percent of all trials had to be repeated.

D. Data Reduction Procedures

As indicated in Chapter IV, C. 6., a team of two analysts was required to operate the analysis projector and the sonic digitizer equipment. The operating procedures for these items are contained in operator's manuals and are not described here. One procedure that does merit mention is the method used by the analysts to "digitize," on the screen, the image of the light spot produced by the test weapon. Because the light spot often appears as a trace on the screen, it was necessary to develop a set of standard rules to insure that light traces were all "digitized" in the same manner. Similarly, scoring rules had to be developed for distinguishing hits from near misses. The procedu s and rules used in this study are contained in Appendix 11.

VI. RESULTS AND INTERPRETATIONS

Results will be discussed in two major sections; the first dealing with data concerning the general aiming and firing characteristics of the sample as a whole, the second dealing with the effects of the seven independent variables under consideration on aiming and firing performance.

A. General Aiming and Firing Characteristics

1. Pre-Shot Variability

Aiming variability patterns from trial onset to one second following the first shot were assessed at .2 second intervals for two trial conditions representing opposite extremes of aiming steadiness as determined from analysis of variance results. Horizontal (σx) and vertical (σy) variability were determined separately, and are depicted in Figures 24 and 25, respectively. Each point on the graphs was determined by calculating the standard deviations of aiming positions for all 16 subjects (where such data were available) at intervals of .2 seconds prior to the first shot and at similar intervals up to one second after the first shot. It can be seen that the number of cases on which these SD's were based varied, particularly for pre-shot intervals (N's are shown for points on the figures calculated from data involving less than the total sample). Consequently, the SD's were multiplied by the reciprocal of the mean coefficent for their respective n's, thereby rendering the various estimates of σ theoretically comparable.

Condition #71, represented by the solid lines in the Figures, was estimated from analysis of variance results to be the steadiest of the 192 trial conditions, consisting of a test weapon with a short, light trigger pull and

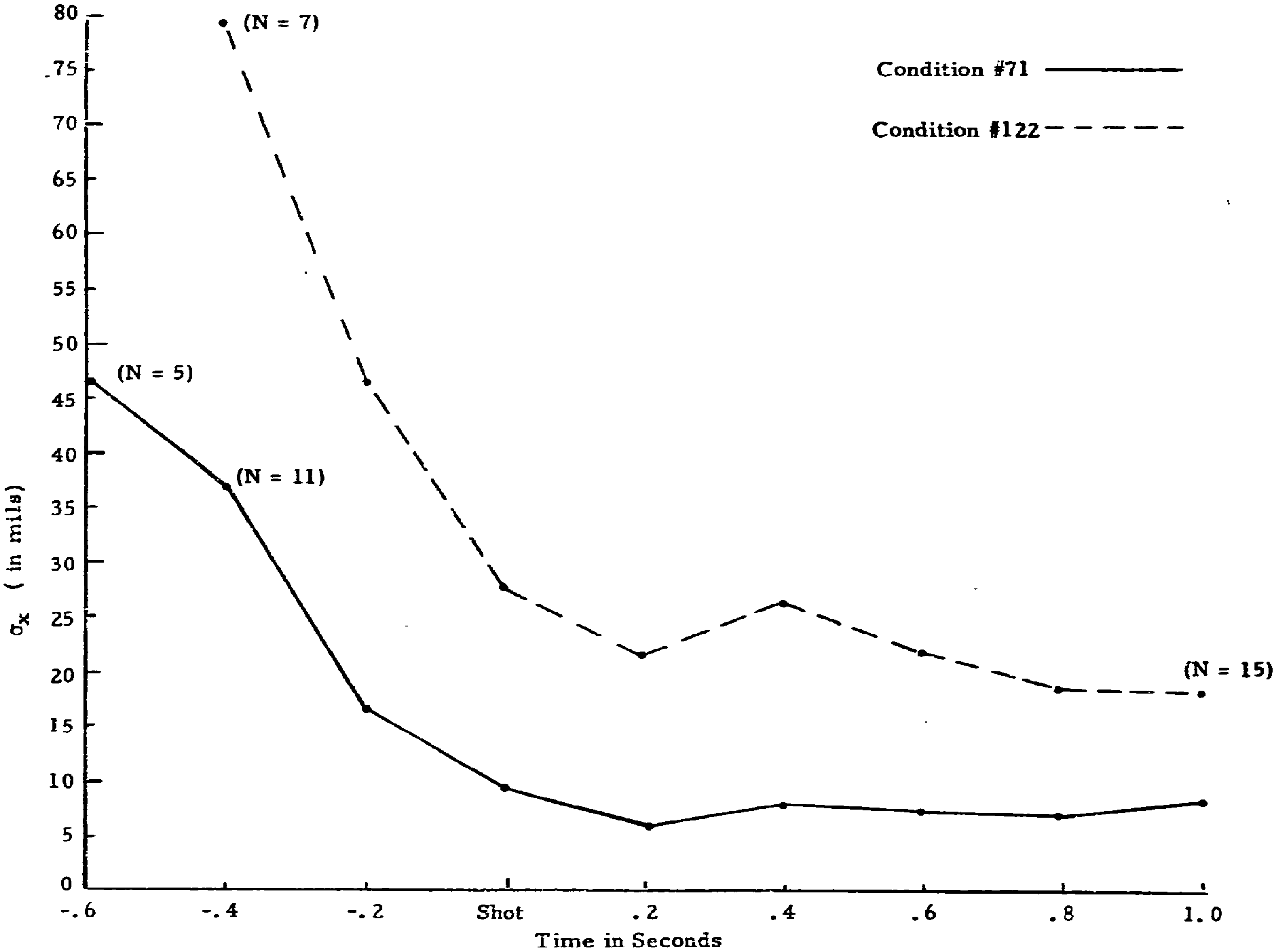

Figure 24. Group Horizontal Aiming Variability at .2 Second Intervals Prior to and Succeeding the First Shot.

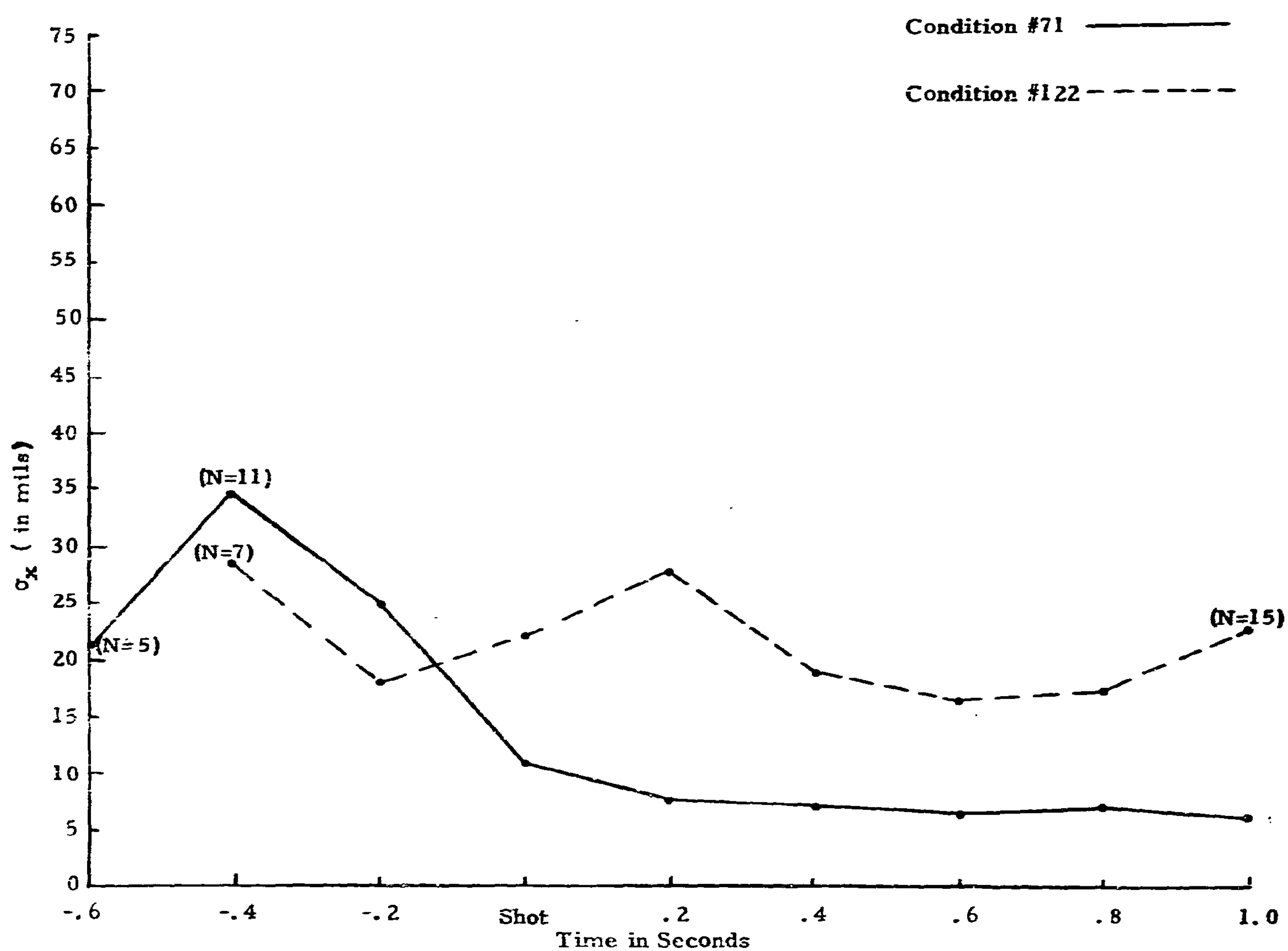

Figure 25. Group Vertical Aiming Variability at .2 Second Intervals Prior to and Succeeding the First Shot.

moderate grip angle operated from the 2-hand hold against a 40 meter, 4 second, stationary target. While the shape of the curves for this condition is generally similar to other findings, it should be noted that the asymptotic levels achieved after the first shot for both horizontal and vertical dispersions are somewhat above 20 digitizer units, or approximately 6 mils.* This may represent greater variability than curves generated by repeated measures on the same subject, since our curves represent "Zeroing In" data from 16 different individuals, each of whom may have a different concept of the target's center of mass, and of the appropriate sight picture. Furthermore, pre-shot variability on these data may be higher than what is conventionally determined, since random appearance of the target at one of three distinctly different positions caused different subjects to approach the target from different directions prior to their first shot. Finally, it may be noted that variability at the first shot is somewaht higher both vertically and horizontally than it is at any subsequent interval. This may indicate that subjects tended to fire their first shot before actually settling in on the center of mass. Since this is a stationary target condition, subjects had no clue as to target exposure time. One might be tempted to speculate that subjects were rushing their first shot in anticipation of a 2 second trial. Time to first shot data, however, discussed later in this chapter, suggest that this was not the case.

Condition #122, represented by the dashed lines in Figures 24 and 25, was determined to be the most variable of the trial conditions. This condition was defined by a test weapon with a long, heavy trigger pull and extreme grip angle operated from the 1-hand hold against a 10 meter 2 second, moving target. These curves show considerably more variability at most points both vertically and horizontally than do their counterparts for condition #71. This was to be expected, since the target was moving

*It has been determined that for this study a 1 mil variation in aim was equivalent to 3.23 units on the digitizer screen.

rapidly for a short period of time and provided a greater "hit" area. At 2 points, however, vertical dispersion (σ y) appeared to be less for condition #122 than for #71. These points represent dispersions at .4 and .2 seconds prior to first shot. This may, of course, be primarily attributable to large error variances at these points in the trial, but might also reflect the fact that the center of mass of the 10 meter target presented in condition #122 was approximately 10 inches lower on the screen than that of the 40 meter target (in condition #71), putting it closer in vertical distance to the aiming point of the subject's "ready" position at trial onset.

2. Subject Bias with Regard to Center of Mass

All subjects were carefully instructed to aim for the center of mass of the target on all trials, and they were shown the actual center of mass (CM) for each target size. Nevertheless, a spot check was made for indications of constant aiming errors in either the vertical or horizontal direction. Data from a sample of four different trials were taken from among those characterized by 4 second, stationary, 40 meter target conditions. Given the size of the target and the coordinates of the reference point (the lower left corner of the target), the coordinates for the CM were determined and compared against the mean horizontal and vertical coordinates (at .2 second intervals after the first shot to the end of the trial) of each subject for each trial.

Analysis for constant vertical aiming error showed no general tendency to aim either above or below the CM. The mean of the Y coordinates for all 16 subjects over the 4 sample trials was 32.61 digitizer units above the reference point, as compared to 34.13 units for the CM. This is a difference of only 1.52 units, or approximately 1/2 mil.

There did occur, however, constant vertical aiming errors among individuals in the sample. If no consistent vertical errors were occuring, we would expect a given subject's mean Y coordinate for any trial to be above or below that of the CM with equal probability. If such were the case, then the expected number of subjects showing mean coordinates to be all above (or all below) that of the CM for the 4 sample trials would be 2 from our total subject sample of 16. In actual fact, 8 (50%) of our sample showed such consistency over all four trials. A Chi-square one-sample test shows this to be highly significant ($X^2 = 20.57$, d.f. = 1, $p < .001$), indicating that a number of these 8 subjects were indeed aiming at a point consistently above (4 subjects) or consistently below (4 subjects) the center of mass of the target. Taken alone, this finding does not suggest the reason for these aiming errors, nor does it tell us which or how many of these 8 subjects were exhibiting a true constant aiming error. To shed more light on these questions, another sample of 4 trials was drawn from the 4 second, stationary, 10 meter target conditions and similarly analyzed. In this case, 9 of the 16 subjects showed constant aiming errors over all 4 sample trials, again a highly significant finding ($X^2 = 28.00$, d.f. = 1, $p < .001$). Of these 9, 4 were consistently below the CM and 5 above. Four of these 9 subjects were among those who had shown consistent aiming errors in the same direction (3 high and 1 low) under 40 meter target conditions. It can be assumed with some confidence, then, that at <u>least</u> these 4 subjects were exhibiting a true constant aiming error during the course of the experiment. Two possible reasons for such errors are immediately evident:

a. Incorrect estimate of the center of mass.

b. Incorrect sight picture.

A comparison of the magnitudes of error between 10 meter and 40 meter conditions suggests that all 4 subjects were aiming consistently at a point on the target other than the actual CM. If the errors were attributable to a consistently incorrect sight picture, they would not be expected to vary in magnitude with target size. For each of our 4 subjects, however, the mean vertical deviation from the center of mass was 3 to 4 times greater with the 10 meter target (12 inches high) than with the 40 meter target (3 inches high). Each of the four subjects, then, appear to have been aiming consistently at a point other than the actual center of mass, the distance between this point and the CM expanding with increasing target size. Three of these four subjects appeared to be aiming at a point roughly halfway between the actual CM and the base of the "head" of the target, or in the upper "chest" area. The fourth subject appeared to be aiming at a point roughly midway between the CM and the bottom of the target. Since the E target represents a rough facsimile of a kneeling man, this would put his aiming point approximately in the genital area, the psychological implications of which will not be pursued here.

Similar analyses were performed to detect constant horizontal error. Again, no general tendency to aim either to the left or right was found. Six of the 16 subjects showed a consistent horizontal aiming bias over the four trials employing the 40 meter target, a number significantly above chance (X^2=9.14, d.f. = 1, $p<.01$), and for the 10 meter target trials, seven subjects showed a consistent horizontal error (X^2=14.29, d.f. = 1, $p<.001$). Four of these subjects showed constant horizontal error for both 10 meter and 40 meter conditions in the same direction, three to the left of the CM, and one to the right. In these cases the mean errors for 10 meter conditions were somewhat greater than for the 40 meter conditions, but not enough to justify the position that the subjects were aiming for a point to the left or right of the CM. It seems more likely that these errors, smaller in magnitude than those found for the vertical coordinates, represent either slight but consistent error in the sight picture or a tendency for the test weapon to deflect to one side with each trigger pull.

In summary, then, our data suggest that, while there is no consistent group aiming bias, a number of subjects do tend to aim at points above or below the center of mass, and others tend to show slight constant errors to the left or right of the CM.

B. Effects of the Independent Variables on Aiming and Firing Performance

1. Operational Definitions of Performance Variables

As described in Chapter III, E. 3., our experimental design lends itself to analysis of variance which was used to determine the effects of the seven independent variables and their interactions on six performance measures derivable from the raw data. A sample of the trial data in its raw printed form is pictured in Figure 26. The one complete trial shown here was coded (as were all others) for appropriate computer identification of the data, and is interpreted for the reader in Figure 26. The first line for this trial identifies the subject and trial condition. The second line gives the y followed by the x coordinate* for the reference point, defined as the lower left corner of the target, fixing the target position on the digitizer screen. Coordinates preceded by the letter "P" represent aiming locations from the first frame on which the IR spot could be located through successive frames to the first shot (each frame representing a time interval of .05 seconds). Coordinates for the first and succeeding shots are preceded by the letters "H" (hit) or "M" (miss). Each shot is followed by a 4-digit number (preceded by the letter "T") representing the time in milliseconds that the shot occurred after trial onset. Unlabeled (indented) coordinates represent aiming position at consecutive .2 second intervals following the first shot to termination of the trial (E).

---

*Orientation of the digitizer during data recording yielded printed coordinates in reverse of the usual order. Coordinate values were also reversed, decreasing rather than increasing from bottom to top and from left to right. These facts were taken into account, where appropriate, in assessing results.

T3856	
0650,1014	
E	
M0026	Subject M, trial condition #26
R1064,1068	Reference coordinates, lower left corner of target
P0982,1268	
P0962,1191	
P0915,1174	
P0875,1155	
P0854,1137	Coordinates at .05 second intervals preceding first shot
P0846,1070	
P0856,1065	
P0844,1038	
P0826,1032	
H0815,1016	Coordinates for first shot (hit)
T0975	Time from trial onset to first shot (0.975 seconds)
0888,1095	
H0890,1059	Coordinates at successive .2 second intervals following first shot
T1238	
0850,1055	
M0820,1027	Coordinates for third shot (miss)
T1487	
0831,1066	
0813,0998	
H0779,1021	
T1901	
0796,1054	
E	End of trial
M0027	
R1066,1068	

Figure 26. Sample of Trial Data in Raw Printed Form.

From these kinds of data our performance measures were derived for each trial. Four of these measures could be obtained directly from the raw data, e.g., from the trial shown in Figure 26:

- Time to first shot = 0.975 seconds
- Time to 1st hit = 0.975 seconds
- Number of hits = 3
- Percent hits = 75%

Measures of vertical and horizontal aiming dispersion were derived, respectively, by calculating the standard deviations of the y and x coordinates for all aiming points at .2 second intervals following the first shot, and multiplying these by the reciprocal of the mean coefficient to obtain a better population estimate. Finally, values for 1-hand hold were adjusted to compensate for varying mean muzzle-calibration values (muzzle to screen distance) between 1-hand and 2-hand holds for a given subject. For example, from the raw data in Figure 26, y coordinates for the .2 second intervals following the first shot (the first number of each pair) yield an uncorrected standard deviation of 31.79. Since $n = 5$, this value is multiplied by the corresponding reciprocal of the mean coefficient (Grubbs, 1964), giving a σ_y estimate of 37.80. Since this trial represents a 1-hand hold condition, and since the subject (M) showed a mean muzzle to screen distance 3% greater for the 1-hand than the 2-hand hold, the σ_y value was reduced by 3% to 36.67, making it experimentally comparable to that of the 2-hand hold for this subject. The same procedure was followed in the estimation of both x and y dispersions for all trials.

It should be mentioned here that few, if any, of the performance measures defined above can meet the rigid theoretical assumptions underlying the analysis of variance approach. A survey of research literature would, in fact, show that these assumptions are seldom even tested, let alone met. Experience has shown that the F-test is sufficiently robust to tolerate even relatively extreme deviations from normality, homogeneity of variance, etc., still yielding reasonably accurate probabilities. Furthermore, it is the only test available which can assess the great variety of interactions which might be critical to the correct interpretation of the results of this study. Various non-parametric tests were originally considered for this analysis, but none were found that could remotely approach the yield or the power of an analysis of variance when applied to the body of data available. Therefore, analyses of variance were run directly on the performance measures as defined above, without resorting to questionable data transformations.

Each of the following sections is devoted to the presentation and discussion of analysis of variance findings regarding the effects of the 7 target, weapon, and human performance variables on a particular dependent measure. While all significant ($p < .05$) results for each measure are listed, not all are discussed. With 127 analyzable components for each dependent measure, about 6 or 7 of these would be expected to exceed the .05 level of significance by chance. Therefore, most of the discussion centers on those factors exceeding the .01 level. Furthermore, a fair number of significant higher order interactions will be ignored since they do not lend themselves to coherent description or interpretation.

In analyzing these data, the method of unweighted means was employed to account for occasional unequal cell frequencies resulting from lost trials. Lost trials occurred primarily as the result of a subject being unable to fire a shot before termination of a trial, thereby yielding no data from which to compute dependent measures. For five of our dependent measures, such trials represented a very small proportion of the total number (3072), and were not considered sufficient to affect the outcome of the analysis. The sixth measure, however, time to first hit, was found to contain too much lost data to produce meaningful analysis of variance results. This was attributable to the fact that many trials, particularly those presenting 2 second, 40 meter targets, produced no hits (although at least one shot was generally fired). It is evident that in this case the method of unweighted means would produce extremely biased estimates of mean time to first hit for trial conditions in which hits often failed to occur, rendering the analysis of such data meaningless. Under these circumstances, it is felt that time to first hit might better be inferred indirectly by reference to results on other dependent measures such as time to first shot and percent hits.

2. Effects of the Independent Variables on Horizontal Aiming Dispersion

Significant effects on horizontal dispersion are listed in Table 3. For reader reference, Table 4 gives the mean σ_x for each of the 192 trial conditions in digitizer units. In this and succeeding sections discussion will focus on the effects of each independent variable taken by itself, with interactions being discussed where they are deemed relevant. All tables describing σ_x or σ_y means were derived directly from computer printout data, which defined these means in digitizer units. To convert any such table value to its equivalent in mils requires only that the reported value be divided by 3.23. On the other hand, figures dealing with such values are already presented in mils.

Table 3

Significant Effects on σx of Grip (G), Slack (S), Force (F), Hold (H), Range (R), Time (T) and Motion (M).

Source	Sum of Squares*	d.f.	Mean Square	F	p
G	2460.142	1/15	2460.142	8.62	.011
S	10169.801	1/15	10169.801	42.09	<.001
F	3257.000	1/15	3257.000	10.82	.006
H	6004.145	1/15	6004.145	34.64	<.001
R	68160.875	2/30	34080.437	120.38	<.001
T	1027.509	1/15	1027.509	7.16	.018
M	46473.023	1/15	46473.023	70.44	<.001
SxF	2057.239	1/15	2057.239	19.88	<.001
GxT	549.829	1/15	549.829	7.54	.015
SxT	1202.080	1/15	1202.080	12.88	.003
RxM	6564.148	2/30	3282.074	25.71	<.001
TxM	489.772	1/15	489.772	10.17	.007
GxSxR	766.430	2/30	383.215	4.30	.028
SxHxM	697.776	1/15	697.776	12.62	.003
GxRxM	707.125	2/30	353.563	4.01	.029
SxRxM	896.425	2/30	448.213	4.60	.019
GxSxFxM	802.967	1/15	802.967	11.34	.004
SxFxHxM	211.532	1/15	211.532	5.37	.035
GxSxHxRxT	322.709	2/30	161.354	5.17	.012
GxFxHxRxM	714.397	2/30	357.1[illegible]9	4.52	.020

*Error sums of squares not listed.

Table 4.

Mean σ_x for Each of the 192 Trial Conditions in Digitizer Units

Grip Angle	Trigger Slack	Trigger Force	Hand Hold	10 meters 2 sec. Sta.	10 meters 2 sec. Mov.	10 meters 4 sec. Sta.	10 meters 4 sec. Mov.	25 meters 2 sec. Sta.	25 meters 2 sec. Mov.	25 meters 4 sec. Sta.	25 meters 4 sec. Mov.	40 meters 2 sec. Sta.	40 meters 2 sec. Mov.	40 meters 4 sec. Sta.	40 meters 4 sec. Mov.
Mod.	Long	Lt.	1	25.7	32.9	26.1	39.0	20.6	22.0	[illegible]	22.7	18.4	17.4	15.9	23.5
			2	24.5	30.6	22.3	36.1	18.6	19.3	16.9	22.9	12.1	18.0	14.8	18.3
		Hvy.	1	31.0	33.8	32.3	39.1	28.3	32.1	20.6	26.7	20.9	25.5	18.2	29.1
			2	25.4	41.0	27.4	39.3	20.0	25.3	18.2	24.6	14.3	21.0	18.2	29.7
	Short	Lt.	1	21.1	36.7	21.0	39.3	19.9	23.4	15.2	21.6	18.2	26.8	14.8	18.4
			2	20.8	40.2	16.5	34.7	11.3	21.6	13.6	19.3	10.4	18.7	11.6	18.9
		Hvy.	1	21.8	32.9	20.8	35.1	18.5	23.5	16.9	23.7	19.0	23.9	15.1	21.7
			2	18.3	30.6	19.8	32.9	19.4	20.6	16.5	18.8	19.5	19.8	12.7	20.8
Ext.	Long	Lt.	1	32.5	41.4	26.9	36.4	16.1	31.0	19.9	27.8	21.3	25.0	16.4	28.1
			2	23.2	34.4	23.5	44.4	17.5	28.8	17.5	23.2	15.5	18.1	16.8	21.9
		Hvy.	1	34.2	41.6	31.4	37.6	31.4	27.9	21.9	31.4	23.4	31.2	21.6	33.8
			2	27.1	39.0	29.0	39.3	19.2	28.7	20.2	27.6	22.8	28.1	17.7	26.7
	Short	Lt.	1	27.6	41.4	20.6	36.1	18.6	31.1	17.0	23.4	18.7	25.0	14.7	18.2
			2	23.1	31.7	19.8	30.9	20.3	22.3	18.5	21.5	15.0	19.8	12.7	13.7
		Hvy.	1	23.3	36.7	22.7	38.3	17.5	28.2	17.7	23.7	15.5	26.2	15.0	20.4
			2	31.7	35.6	20.5	34.5	15.5	26.0	16.3	24.5	15.3	15.3	13.9	16.7

Grip Angle. A small but significant ($p = .011$) overall difference was found for σx between the moderate and extreme grip angles. Trial conditions employing the moderate grip showed an overall mean σx of 23.14 digitizer units as compared to 24.90 with the extreme grip angle. This represents a mean difference of 1.76 digitizer units (about .5 mils) favoring the moderate grip angle. The reliability of this finding may be open to question. The significance level approaches, but does not exceed .01, and the effect was not found for vertical dispersion (σy). One possible reason for the difference in horizontal aiming error (if the effect is, in fact, reliable) is that the circumference of the extreme grip angle is smaller than the standard (moderate) grip. This might well require a tighter grip to keep it from rotating slightly in the hand with each trigger pull. If such is the case, it should be reflected, as it was, by a higher mean σx value for the extreme grip angle, and also, perhaps by a greater difference under long pull conditions than is found with the short pull (grip x slack interaction). It seems reasonable that if the extreme grip tends to twist more in the hand with trigger pulls, the longer pull would exaggerate the effect. This interaction was not, in fact, significant, but Table 5 shows the mean σx to vary in the direction suggested by this interpretation.

Table 5.

Mean σx for Moderate and Extreme Grip Angles over Long and Short Trigger Pull Conditions

	Long pull	Short pull
Moderate	24.72	21.67
Extreme	27.10	22.87

The most highly significant of those interactions involving grip angle was grip x slack x force x motion ($p = .004$), described by Table 6.

Table 6.

Mean σx for Moderate and Extreme Grip Angles over Different Combinations of Trigger Slack and Pull Force Under Stationary and Moving Target Conditions

Stationary Targets

	Light pull		Heavy pull	
	Long pull	Short pull	Long pull	Short pull
Moderate	20.19	16.40	22.93	18.23
Extreme	20.80	18.92	24.99	19.03

Moving Targets

	Light pull		Heavy pull	
	Long pull	Short pull	Long pull	Short pull
Moderate	25.20	26.62	30.57	25.38
Extreme	30.05	26.29	32.54	27.19

Without attempting a detailed interpretation of this complex effect, it can simply be noted that the greatest difference in horizontal aiming error between moderate and extreme grip angle appears with the long, light trigger pull under moving target conditions.

Trigger Slack. The overall effect of trigger slack was highly significant ($p < .001$), with conditions employing the long pull showing a mean σx of 25.88 as compared to 22.16 for short pull conditions. On the whole, then, the short trigger pull produces less horizontal aiming variability, with a mean σx less than that of the long pull by 3.72 units, or approximately 1.25 mils.

Among the more significant interactions involving trigger slack were slack x time ($p = .003$) and slack x hold x motion ($p = .003$), the nature of which are shown by Tables 7 and 8 respectively.

Table 7.

Mean σx for Long and Short Trigger Pulls over 2 and 4 Second Trial Conditions

	2 second	4 second
Long pull	25.86	25.96
Short pull	23.47	21.07

Table 8

Mean σx for Long and Short Trigger Pulls within 1 and 2 Hand Hold and Stationary and Moving Target Conditions

	Stationary target		Moving target	
	1-hand	2-hand	1-hand	2-hand
Long pull	24.20	20.26	30.61	28.57
Short pull	18.99	17.35	28.14	24.59

The means in Table 7 seem to suggest that, with a short trigger pull, subjects tend to become progressively steadier with time after initially "zeroing in" and firing at the target. There is, however, no corresponding decrease in σx with the long pull. It may be that the baseline horizontal aiming variability inherent in the long pull simply does not allow for a further increase in steadiness during 4 second trials beyond that attained during the first 2 seconds.

A similar interpretation might help explain the slack x hold x motion interaction depicted by Table 8. While horizontal aiming variability declines for long and short trigger pulls with the 2-hand holds for both stationary and moving target conditions, the decline appears to be less for the short pull with stationary targets while the reverse holds for moving target conditions. At least a partial explanation for this might be the existence of a "ceiling effect" with respect to short pull, 2-hand hold, stationary target conditions. These conditions may approach the average subjects' physiological limit for aiming steadiness, thereby not allowing for further decrease in aiming error for those conditions.

<u>Trigger Pull Force</u>. As might be expected, the mean overall σx for heavy trigger pull conditions is significantly greater than for the light pull ($p = .006$), with means of 25.08 and 22.96, respectively (a difference of 2.12 units or approximately .7 mils). The true extent of the difference, however, might well have been attenuated by the fact that what was originally thought to be a 12 pound heavy pull force for the short trigger pull condition was determined, after data collection, to be approximately 5 pounds - nearly identical to that of the short, light pull configuration. It has not been conclusively determined whether this represented a progressive weakening of the spring mechanism during the course of the study, or whether, in fact, this trigger assembly had produced a short, light pull from the onset. Pertinent to this issue is the significant ($p < .001$) slack x force interaction, illustrated by Table 9.

Table 9.

Mean σx for Long and Short Trigger Pulls over Light and Heavy Pull Conditions

	Light pull	Heavy pull
Long pull	23.96	27.79
Short pull	21.95	22.36

This table shows that virtually all of the observed difference for trigger pull force on horizontal dispersion is found within the long pull condition. This is open to 2 interpretations: a) there was, in fact, never a short, heavy pull condition, or b) there was a progressively deteriorating short, heavy pull during the course of data collection, the effect of which was negligible. Since neither interpretation can be conclusively verified, we must, unfortunately, yield to the more conservative, and tentatively conclude that the short, heavy trigger pull configuration was never adequately tested.

Hold. A consistent, highly significant, overall difference was found in horizontal aiming error between the subjects' use of the 1- or 2-hand hold, the 2-hand hold showing a steadier horizontal aiming pattern (σx = 22.60) than did the 1-hand hold (σx = 25.43), a mean difference in σx equivalent to approximately .9 mils.

The only highly significant ($p < .01$) interaction effect involving the hold variable was the slack x hold x motion interaction discussed earlier with respect to trigger slack and illustrated in Table 8.

Target Range. The overall effect of simulated target range (size) was, not surprisingly, profoundly significant. While subjects were told to aim for the center of mass, they were also instructed that they were to obtain as many hits as possible during the course of a trial. This implied that they were to fire as quickly as possible once they felt they were aiming within the target. A closer (larger) target, then, would require considerably less aiming precision than one simulated at a greater distance. That the subjects behaved accordingly is quite obvious. For the target at a simulated distance of only 10 meters, the overall mean σx was 30.67 as compared with 21.85 and 19.54 for 25 and 40 meter targets, respectively. Quite clearly, then, subjects' aiming precision increased as simulated target distance increased (or target size decreased)

The only highly significant interaction effect involving target range was range x motion as shown in Table 10. It can be seen

Table 10.

Mean σx for Each of the 3 Simulated Target Ranges over Stationary and Moving Target Conditions.

	Stationary	Moving
10 meters	24.67	36.67
25 meters	18.85	24.85
40 meters	16.58	22.49

from this table and from Figure 27 that a far greater increase in horizontal aiming error occurs from stationary to moving target conditions for the 10 meter target than for the 25 and 40 meter ranges. It should be noted, in this regard, that in order to simulate speeds of 15 feet per second at 3 different target ranges the actual distance (hence speed) traveled across the subjects' field of vision must be greater for closer simulated distances over the same amount of time. Consequently, in this study the length of the arc traversed during a 4 second trial by a 10 meter target along a screen 10 feet from the subject was about 18 feet (4.5 feet per second), as compared to about 7.3 feet (1.8 feet per second) and 4.5 feet (1.1 feet per second) for the 25 and 40 meter targets, respectively. With respect to the subjects, then, the 10 meter targets moved across the screen further and faster than the 25 and 40 meter targets, making it more difficult to track and leading to a greater increase in horizontal aiming error.

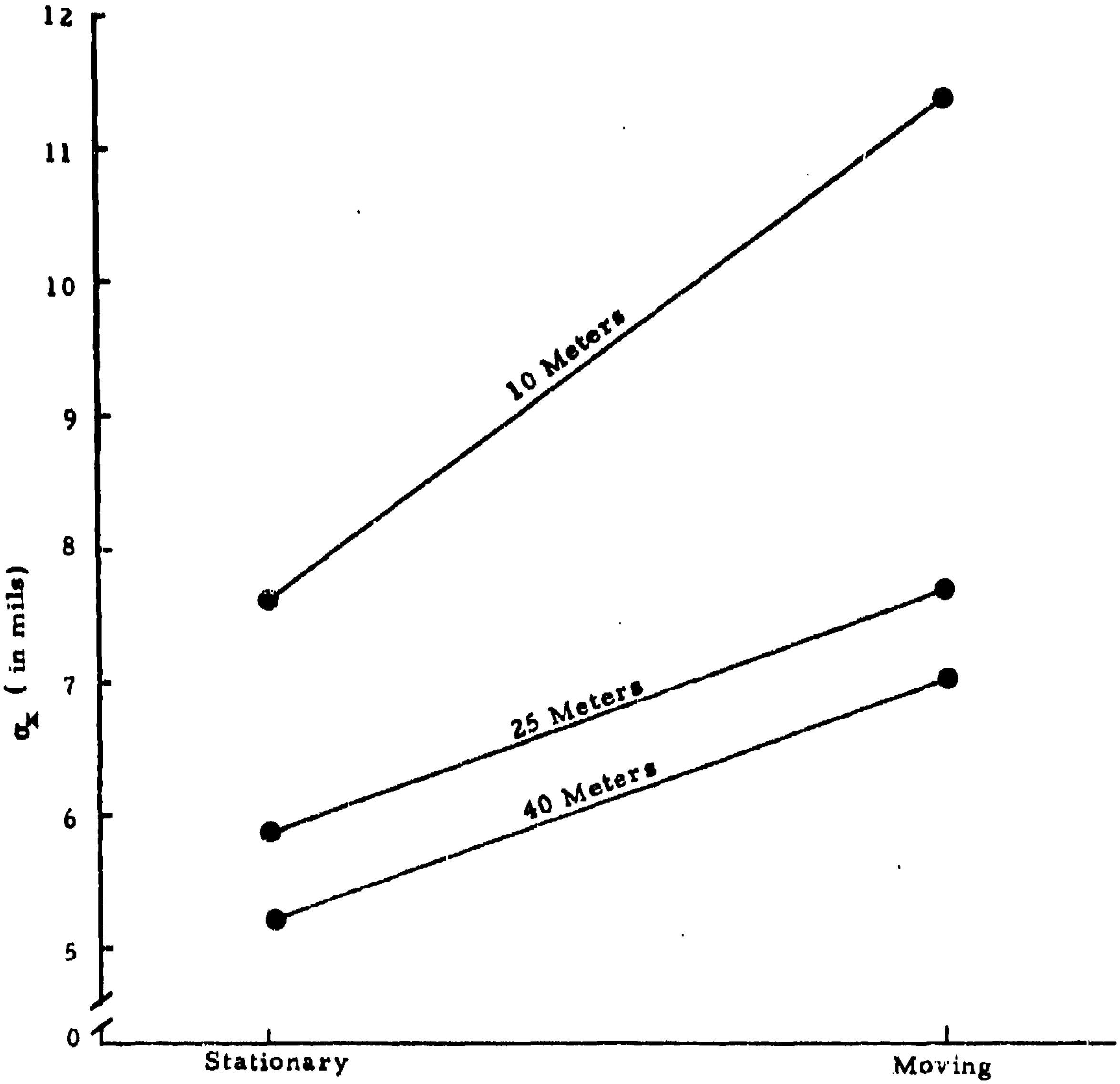

Figure 27. Target Motion x Range Interaction on σ_x

Target Exposure Time. The overall effect of target exposure time was significant ($p = .018$) but only marginally so under the ground rules of this analysis. Horizontal aiming error was slightly greater for 2 second target exposures than for 4 second exposure times ($\sigma x = 24.52$ and 23.50, respectively). This small difference would not be expected to hold for all trial conditions. Two significant interactions involving exposure time exceed the .01 level. One was the slack x time interaction ($p = .003$) discussed earlier with regard to trigger slack and described in Table 7. It was shown that the longer target exposure time reduced mean horizontal aiming variability under short trigger pull conditions, but did not affect variability with the long pull.

Another significant effect was the time x motion interaction ($p = .007$) shown in Table 11.

Table 11.

Mean σx for 2 and 4 Second Target Exposure Times over Stationary and Moving Target Conditions

	Stationary	Moving
2 seconds	20.87	28.17
4 seconds	19.20	27.83

This effect suggests a slight reduction in horizontal aiming error with stationary targets, but virtually no reduction under moving target conditions. It may be that subjects continue to steady down somewhat during the third and fourth seconds of stationary conditions, but are unable to do so when tracking moving targets.

Target Motion. As expected, horizontal aiming error was far greater ($p < .001$) with moving targets than with stationary targets, the former yielding an overall mean σ_x of 28.00 as compared to 20.03 for the latter. This represents a mean σ_x difference of approximately 2.7 mils.

The more significant interactions involving target motion were discussed earlier and are illustrated by Tables 6, 8 and 10. Table 10 and Figure 27 best illustrate the most significant effects of target motion on horizontal aiming error. At all simulated target distances, aiming error increases from stationary to moving target conditions, with the greatest increase occurring in the 10 meter range.

3. Effects of the Independent Variables on Vertical Aiming Dispersion

Significant effects on vertical dispersion (σ_y) and the mean σ_y for each of the 192 trial conditions in digitizer units are given in Table 12 and 13 respectively.

Grip Angle. This variable appears to have had little, if any, influence on vertical aiming error. The main effect was not significant, with moderate and extreme grips showing virtually identical σ_y means of 22.61 and 22.04, respectively. No interactions involving grip angle exceeded the .01 level of significance.

Trigger Slack. As with horizontal dispersion, conditions involving the short trigger pull produced considerably less vertical

Table 12.

Significant Effects on σ y of Grip (G), Slack (S), Force (F), Hold (H), Range (R), Time (T) and Motion (M)

Source	Sum of Squares*	d. f.	Mean Square	F	p
S	13031.188	1/15	13031.188	48.10	<.001
F	3760.496	1/15	3760.496	14.92	.002
H	2741.732	1/15	2741.732	16.39	.002
R	36774.578	2/30	18387.289	97.30	<.001
M	11687.824	1/15	11687.824	97.47	<.001
SxF	1316.685	1/15	1316.685	8.61	.011
GxT	524.419	1/15	524.419	4.79	.045
FxM	465.113	1/15	465.113	10.40	.006
RxM	615.034	2/30	307.517	3.66	.038
GxHxR	610.699	2/30	305.350	4.95	.014
SxFxT	528.586	1/15	528.586	10.40	.006
FxRxM	802.587	2/30	401.293	4.92	.015
SxFxHxRxM	283.543	2/30	141.771	3.69	.038
GxSxFxRxTxM	762.434	2/30	381.217	4.44	.021

* Error sums of squares not listed.

Table 13.

Mean σ_y for Each of the 192 Trial Conditions in Digitizer Units

Grip Angle	Trigger Slack	Trigger Force	Hand Hold	10 meters 2 sec. Sta.	10 meters 2 sec. Mov.	10 meters 4 sec. Sta.	10 meters 4 sec. Mov.	25 meters 2 sec. Sta.	25 meters 2 sec. Mov.	25 meters 4 sec. Sta.	25 meters 4 sec. Mov.	40 meters 2 sec. Sta.	40 meters 2 sec. Mov.	40 meters 4 sec. Sta.	40 meters 4 sec. Mov.
Mod.	Long	Lt.	1	23.3	29.8	26.0	34.5	20.8	23.4	19.7	20.8	18.7	21.4	19.8	20.6
			2	31.3	30.7	25.3	29.2	20.8	21.1	20.1	20.7	18.4	23.7	18.2	19.1
		Hvy.	1	34.2	38.2	30.6	32.5	19.2	32.9	23.2	26.5	25.4	21.3	20.6	27.0
			2	26.6	40.8	30.8	29.2	19.2	31.1	18.5	21.9	17.5	25.5	18.3	20.3
	Short	Lt.	1	19.2	28.1	20.8	28.4	19.1	22.5	19.7	20.4	17.6	23.8	16.8	17.7
			2	26.3	31.3	22.7	27.1	15.1	20.3	14.6	17.0	13.2	17.1	12.5	15.5
		Hvy.	1	19.7	29.9	24.7	31.4	19.3	21.5	19.1	22.1	20.8	20.3	17.5	21.0
			2	24.3	23.4	22.4	21.6	14.5	20.4	15.3	19.1	14.0	20.7	14.2	17.9
Ext.	Long	Lt.	1	28.8	25.2	27.8	34.3	17.2	21.9	20.3	20.7	19.9	21.4	18.7	24.0
			2	22.3	28.2	23.2	27.1	14.8	22.7	21.4	18.0	14.8	18.5	15.2	23.9
		Hvy.	1	25.4	36.4	28.6	31.9	25.1	26.8	21.0	27.3	17.0	31.6	21.8	28.6
			2	26.1	32.5	23.3	31.1	23.3	26.6	22.3	21.9	20.8	26.6	20.5	21.7
	Short	Lt.	1	25.0	30.1	20.7	30.0	18.6	15.2	20.6	18.4	14.0	19.5	15.3	15.6
			2	19.5	25.9	18.0	26.3	20.3	16.6	16.5	17.2	13.3	14.6	15.3	17.1
		Hvy.	1	19.5	28.4	23.7	31.6	14.3	21.6	18.4	23.0	19.7	22.9	17.9	19.5
			2	21.6	26.5	22.0	24.7	14.1	23.8	17.7	21.5	13.1	18.2	[illegible]	16.0

aiming error than did those employing the long pull. The difference was highly significant ($p < .001$), with overall σy means of 20.26 as against 24.41 for the short and long pulls, respectively, a difference of 4.15 digitizer units or about 1.4 mils. Thus, the short trigger pull is apparently superior to the long pull with respect to both horizontal and vertical aiming steadiness.

Interaction effects involving trigger slack will be dealt with in the discussion of trigger pull force which follows.

Trigger Pull Force. The overall effect of trigger pull force as with slack, was significant for vertical aiming dispersion as well as for the horizontal. The light pull conditions showed a smaller overall vertical variance with a mean σy of 21.23 as compared to 23.42 for the heavy pull on both the vertical and horizontal dimensions.

We must reiterate, however, that the trigger assembly thought to have been a short, heavy (12 lb.) pull appeared after data collection to have required little more than a 5 lb. pull--virtually equivalent to the short, light pull conditions. Table 14 shows the slack x force

Table 14.

Mean σy for Long and Short Trigger Pulls over Light and Heavy Pull Conditions

	Light pull	Heavy pull
Long pull	22.66	26.16
Short pull	19.79	20.68

interaction ($p = .011$) on σy. Reference to this table along with Table 9, presented earlier, indicates that virtually all of the difference between short and long pull conditions--on both horizontal and vertical dimensions--can be attributed to greater variance shown by the long, heavy pull configuration. Figure 28 illustrates this fact for both σ_x and σ_y. Consequently, we are unable to determine what effect, if any, a <u>true</u> short, heavy pull would have had on aiming error.

One interaction involving pull force and exceeding the .01 level of significance was slack x force x time ($p = .006$), described by Table 15.

Table 15.

Mean σ_y for Long and Short Trigger Pulls over Light and Heavy Pull Force Conditions for 2 Second and 4 Second Target Exposures

	2 second		4 second	
	Light pull	Heavy pull	Light pull	Heavy pull
Long pull	22.56	27.14	22.83	25.30
Short pull	20.44	20.74	19.34	20.84

The long trigger pull increased in mean σ_y from light to heavy pull to a greater extent under 2 second than under 4 second trial conditions. If anything, the opposite wa[illegible]ue with the short pull, with virtually no increase for 2 second trials but a slight rise under 4 second conditions. The reason for this interaction is not clear, and it might be attributable to Type 1 error (no true effect).

Another interaction, force x motion ($p = .006$), also defies simple interpretation. As shown by Table 16, vertical aiming error under heavy

Table 16.

Mean σ_y for Light and Heavy Trigger Pulls over Stationary and Moving Target Conditions

	Stationary	Moving
Light pull	19.61	22.85
Heavy pull	21.03	25.85

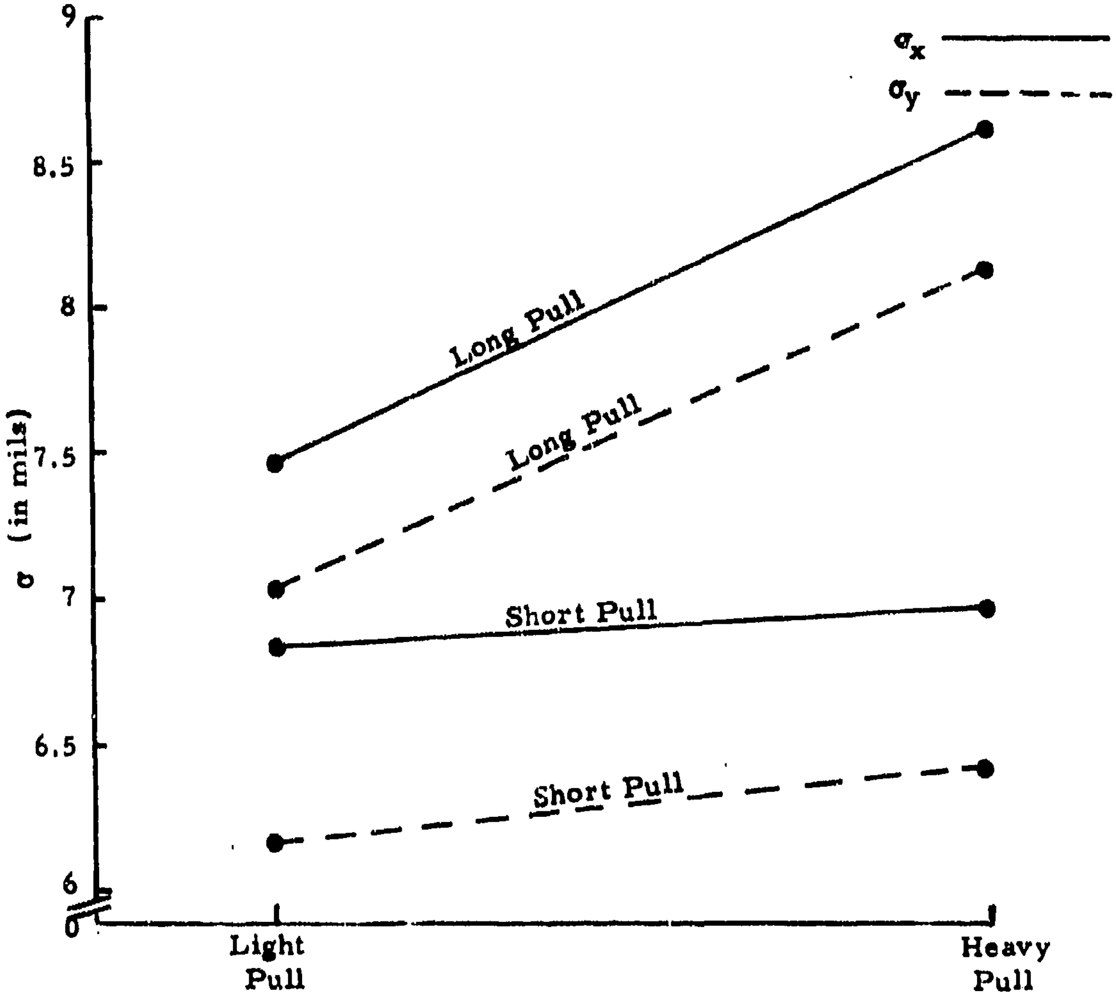

Figure 28. Slack x Force Interaction on Both σ_x and σ_y

trigger pull conditions increases to a greater extent from stationary to moving target conditions than it does with the light pull. As mentioned earlier, the heavy pull was apparently operative only for the long trigger pull configuration. For this reason, the greater effect of target motion on the heavy pull, if a true effect, should be found only within the long, heavy pull condition, yielding a significant slack x force x motion interaction. This effect, in fact, was far from significant ($p = .437$), with the short, "heavy" pull apparently also contributing to the effect, despite its not being a heavy pull at all. We can only conclude, then, that the effect is not replicable if the short, heavy pull was indeed not operative during the course of the study.

Hold. An overall significant difference in σy was also found between 1 and 2-hand hold conditions ($p = .002$) with mean σy's of 23.31 and 21.34, respectively. The same was true with σx, as discussed earlier, and the differences were in the same direction--the 2-hand hold being steadier in both the horizontal and vertical directions.

No interactions involving hold were found to exceed the .01 level of significance, leading us to conclude that the effect is primarily general over all conditions.

Target Range. The overall effect of target range on vertical aiming dispersion was large and highly significant($p < .001$), as it was for horizontal dispersion. Mean values of σy were 27.28, 20.46 and 19.24 for 10, 25 and 40 meter targets, respectively. It can be concluded, therefore, that target range (or size) has a strong effect on aiming variability in general--both horizontally and vertically.

One interaction effect involving target range should be mentioned here, despite the fact that it failed to exceed the .01 level of significance.

The range x motion interaction ($p = .038$) is shown in Table 17. The largest effect of target motion on vertical aiming error occurred with

Table 17.

Mean σ_y for Different Target Ranges over Stationary and Moving Target Conditions

	Stationary	Moving
10 meter	24.67	29.82
25 meter	19.01	22.12
40 meter	17.67	21.11

10 meter targets. While this difference appears marginal at best, given our criteria for significance, it seems reasonable to suggest that it was attributable to the greater speed with which the 10 meter target traversed the screen. It should be recalled that a similar difference occurred for horizontal aiming error, although substantially greater in magnitude and statistical significance ($p < .001$). This difference in magnitude (Figure 29) seems reasonable, since moving targets traversed along the horizontal dimension, so that variations in speed should more profoundly effect aiming accuracy with respect to that dimension.

Target Exposure Time. No main effect of target exposure time was found on vertical aiming variance. The only interaction effect exceeding the .01 level of significance was the slack x force x time interaction ($p = .006$), discussed as a possible Type 1 error with regard to trigger pull force. These facts, along with the tenuous, if true, effects of time on horizontal aiming error suggest little, if any, notable effect of target exposure time on aiming steadiness in general.

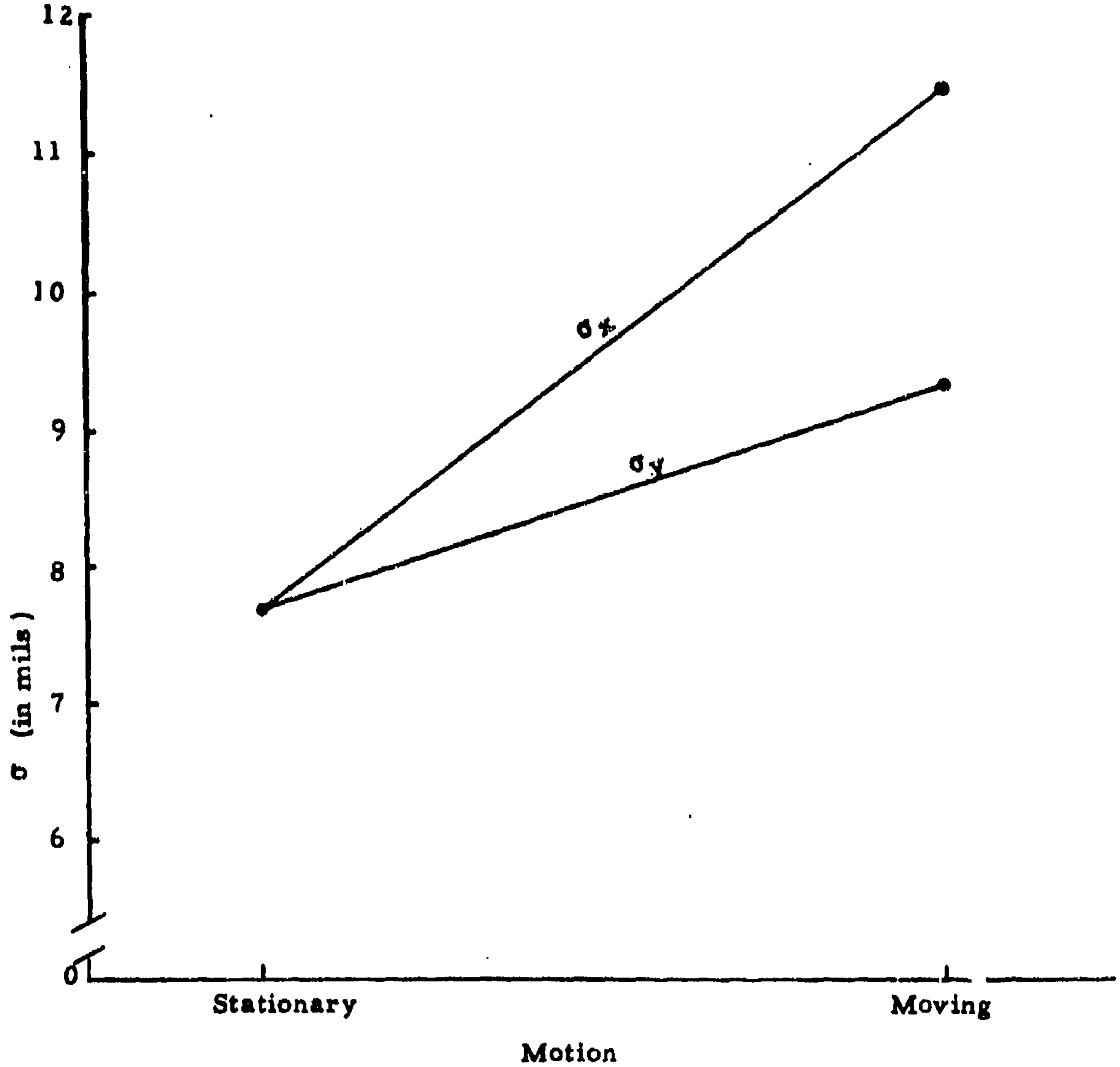

Figure 29. Mean Increase in Horizontal and Vertical Aiming Error for 10 Meter Targets from Stationary to Moving Target Conditions.

Target Motion. The overall effect of target motion on vertical aiming steadiness was highly significant ($p < .001$), yielding mean σy values of 20.32 for stationary targets as against 24.33 on moving target conditions. The magnitude of difference is substantially less than that found for horizontal dispersion, however, with target motion causing a mean σy increase of about 1.2 mils as compared to nearly double the increase (about 2.4 mils) for σx. As suggested earlier with regard to range x motion interactions on σx and σy, target motion (and variations in speed of movement) should affect horizontal aiming variability to a greater extent, since that is the direction of target movement. There is little doubt, however, that horizontal target motion does increase vertical aiming error as well.

The only interaction involving target motion which exceeded the .01 significance level was the force x motion interaction discussed earlier with respect to trigger pull force and illustrated by Table 16. As stated in that discussion, the meaning or reliability of that finding is not clear.

4. Effects of the Independent Variables on Percent Hits

Table 18 summarizes all significant effects of the independent variables on percent hits (# of hits/# of shots in each trial). Table 19 gives mean percent hits for all 16 subjects in each of the 192 trial conditions.

Grip Angle. No overall effect of grip angle on percent hits was found in this study. It should be recalled that a slight but significant effect of grip angle was found on horizontal aiming error, the extreme grip yielding a somewhat larger overall horizontal dispersion. It is reasonable to assume that any weapon configuration that increases aiming

Table 18.

Significant Effects on Percent Hits of Grip (G), Slack (S), Force (F), Hold (H), Range (R), Time (T) and Motion (M)

Source	Sum of Squares*	d.f.	Mean Square	F	p
S	45973.008	1/15	45973.008	33.25	< .001
H	12320.082	1/15	12320.082	5.71	.031
R	1058722.000	2/30	529361.000	319.53	< .001
T	22815.707	1/15	22815.707	28.75	< .001
M	149382.375	1/15	149382.375	129.12	< .001
SxF	6580.090	1/15	6580.090	5.34	.036
SxR	10706.453	2/30	5353.227	10.46	< .001
HxR	2984.874	2/30	1492.437	3.41	.047
RxT	3894.042	2/30	1947.021	9.20	.001
GxSxT	2086.922	1/15	2086.922	10.91	.005
GxSxFxR	3977.650	2/30	1988.825	3.50	.044
GxFxHxT	2200.527	1/15	2200.527	6.20	.026
SxFxHxT	1938.018	1/15	1938.018	5.02	.041
GxSxFxRxT	6374.621	2/30	3187.311	6.13	.006
GxHxRxTxM	3072.975	2/30	1536.487	4.00	.029

*Error sums of squares not listed.

Table 19.

Mean Percent Hits for Each of the 192 Trial Conditions

Grip Angle	Trigger Slack	Trigger Force	Hand Hold	10 m 2 sec. Sta.	10 m 2 sec. Mov.	10 m 4 sec. Sta.	10 m 4 sec. Mov.	25 m 2 sec. Sta.	25 m 2 sec. Mov.	25 m 4 sec. Sta.	25 m 4 sec. Mov.	40 m 2 sec. Sta.	40 m 2 sec. Mov.	40 m 4 sec. Sta.	40 m 4 sec. Mov.
Med.	Long	Lt.	1	92.1	81.2	93.2	82.2	72.0	45.3	61.9	53.7	43.7	35.4	58.3	43.3
			2	92.5	83.8	91.7	77.8	83.6	47.1	77.8	49.0	57.4	33.9	44.7	47.7
		Hvy.	1	84.2	86.9	90.4	71.1	34.4	37.9	46.5	32.6	23.4	25.5	28.8	13.5
			2	89.6	81.1	90.5	81.2	46.7	39.1	71.2	49.6	45.8	29.9	52.2	39.1
	Short	Lt.	1	96.2	81.1	93.4	81.9	54.9	43.2	82.4	62.6	44.1	30.9	51.7	39.1
			2	89.0	84.9	95.1	84.7	65.8	47.5	85.2	67.2	58.0	40.1	66.8	48.1
		Hvy.	1	97.9	68.0	96.8	86.6	68.0	56.4	75.9	58.0	43.4	38.4	57.9	48.9
			2	93.0	74.2	99.2	86.1	72.7	55.0	75.3	66.6	54.2	30.8	58.5	55.9
Ext.	Long	Lt.	1	87.9	90.2	95.2	81.9	60.2	43.8	64.1	54.0	27.5	27.2	43.3	34.6
			2	95.4	75.3	95.3	81.4	64.7	49.3	67.3	53.9	30.1	28.6	59.3	31.6
		Hvy.	1	87.9	59.8	95.8	74.3	53.8	46.8	59.9	38.2	41.7	28.1	34.4	24.1
			2	94.6	74.2	96.4	77.5	61.4	42.6	57.5	46.8	22.8	32.6	38.2	34.6
	Short	Lt.	1	97.9	76.4	97.8	84.0	74.9	60.8	78.2	50.6	39.9	40.6	52.3	40.8
			2	93.6	87.2	94.8	80.7	68.4	53.0	83.6	71.9	48.4	44.2	68.0	43.7
		Hvy.	1	94.9	73.7	98.2	77.1	70.5	37.1	73.2	55.8	38.7	29.1	53.2	38.9
			2	92.2	80.3	97.7	79.9	69.6	36.0	80.8	62.1	51.1	43.9	47.8	29.8

error will decrease percent hits, although the latter effect may not be as reliable since percent hits is also a function of constant aiming error and possible ceiling effects with large targets. Section A. 2. of this Chapter has suggested that a number of subjects did, in fact, show a constant aiming bias over trial conditions, thus affecting their hit probabilities--especially with small targets, where the correlation between percent hits and aiming steadiness should be highest. In any event, the direction of the overall difference between moderate and extreme grips, while not significant was found to favor the moderate grip angle with 63.07% hits over all conditions as compared to 61.65% under extreme grip angle conditions.

It may be asked whether grip angle affects the mean aiming point, i.e., do subjects tend to show a constant difference in where they aim with the different grip angles. For a number of trial conditions, a correlated T-test was run, subjects being compared against themselves on mean aiming points after first shot with moderate and extreme grips. No consistent differences were found on either the horizontal or vertical dimensions. Thus, grip angle does not seem to determine whether a subject aims higher, lower, or to the left or right for this sample.

Two interaction effects involving grip angle were found to exceed the .01 significance level, but neither lends itself readily to interpretation. One of these was the grip x slack x time interaction ($p = .005$) which is presented below in Table 20 for the reader's consideration. This Table suggests that for 2 second target exposures the extreme grip angle yields a lower percentage of hits with longer trigger slack, while for short slack conditions the grips are virtually equivalent. With 4 second target exposures, however, the exact opposite appears to prevail. The reason for this is not clear.

Table 20.

Mean Percent Hits fo[illegible] and Extreme Grip Angles over Light and Heavy Trigger Sla[illegible]tions for 2 and 4 Second Target Exposures

	2 seco		4 second	
	Long pull	Short pull	Long pull	Short pull
Moderate	58.27	62.04	50.42	71.56
Extreme	55.31	62.94	59.98	68.39

A grip x slack x force x range x time interaction ($p = .006$) was also found, but is too complex to present or interpret here.

Trigger Slack. Since the long trigger pull was found to increase significantly horizontal and vertical aiming variability, we should expect that the short pull would yield a greater percentage of hits. This was, in fact, the case, with overall means of 66.23 and 58.49 percent hits ($p < .001$) for short and long pull conditions, respectively. A highly significant slack x range effect ($p < .001$) was also found, and is shown by Table 21.

Table 21.

Mean Percent Hits for Long and Short Trigger Pulls over Different Target Ranges

	10 meter	25 meter	40 meter
Long pull	85.31	53.59	36.59
Short pull	87.82	64.57	46.31

It is apparent from the Table that differences between long and short pull on percent hits are considerably greater under 25 and 40 meter conditions (the smaller targets) than for 10 meter targets. For the latter, the demonstrated effect of trigger slack on aiming steadiness would not be expected to have as great an effect on percent hits, since the relatively large area of this target produces hits in all but the grossest cases of aiming error. It seems, then, that since shots produce predominantly hits for 10 meter conditions, this interaction was attributable to a "ceiling" effect on the influence of slack-induced aiming variability on percent hits under 10 meter target conditions.

<u>Trigger Pull Force.</u> While the overall effect of trigger pull force was not quite significant (p = .056) on percent hits, it is worth noting that the light pull produced a generally greater percentage of hits (64.71) than did the heavy pull (60.01). This would follow from the greater overall aiming variance produced on both the horizontal and vertical dimensions by the heavy pull.

As stated earlier, the overall effects on aiming variability were attenuated by the fact that the heavy pull was apparently inoperative for short trigger slack conditions. Therefore, we look to the slack x force interaction to verify the effect of pull force on percent hits. This effect, while not exceeding .01, was significant (p = .036), and is illustrated by Table 22.

Table 22.

Mean Percent Hits for Long and Short Trigger Pulls over Light and Heavy Pull Conditions

	Light pull	Heavy pull
Long pull	62.31	54.68
Short pull	67.12	65.35

From this it can be seen that by far the greatest reduction in percent hits occurred under long, heavy pull conditions, the configuration which also produced the greatest aiming variability as discussed earlier.

Hold. As might be expected from the overall effects of 1-hand versus 2-hand hold on both horizontal and vertical aiming variance, the 2-hand hold (producing a generally steadier aim) showed a greater overall percentage of hits (64.37) than did the 1-hand hold (60.36). The difference, though not exceeding .01, was significant ($p = .031$).

As shown by Table 23, the hold x range interaction was significant (though marginally--$p = .047$), indicating, if anything, the fact that

Table 23.

Mean Percent Hits for One and Two Hand Holds over Different Target Ranges

	10 meters	25 meters	40 meters
1-hand	85.94	56.58	38.56
2-hand	87.19	61.57	44.33

percent hits is more greatly influenced by aiming steadiness with smaller targets.

Target Range. As expected, target range (or size) was a profoundly significant factor on percent hits ($p < .001$). Despite the fact that larger targets increase overall aiming variance, they also increase the probability of hits as shown by mean percent hits of 86.56, 59.08, and 41.45 for 10, 25, and 40 meter targets, respectively.

Target Exposure Time. Target exposure time also produced a significant difference in percent hits ($p < .001$) with 4 second conditions showing an overall mean percentage of 65.01 vs. 59.64 for 2 second conditions. The extent of this difference is rather surprising, since the effect of target exposure time on aiming steadiness was tenuous. As suggested in Section A.1., however, the prospect of a short (2 second) exposure time may have caused subjects to rush their initial shots, firing before obtaining the correct sight picture, thus leading to a greater percentage of misses on shots fired in the first 2 seconds.

The significant effect of range x time ($p = .001$) again suggests a ceiling effect for 10 meter conditions similar to that shown for slack x range and hold x range. In the present case (Table 24) it appears that rushing the initial shots did not result in as great a percentage of early misses at 10 meters, since for the larger target a careful aim was not required for hits to be scored.

Table 24.

Mean Percent Hits for Different Target Ranges over Two and Four Second Target Exposure Times

	2 second	4 second
10 meters	85.38	87.75
25 meters	55.24	62.92
40 meters	38.30	44.60

Target Motion. Target motion reduced the percentage of hits to a highly significant degree ($p < .001$) with subjects scoring (overall) 69.34% hits for stationary targets, but only 55.39% under moving target conditions. This, of course, can be attributed largely to the increase in aiming variability with moving targets, particularly on the horizontal dimension.

5. Effects of the Independent Variables on Number of Hits

Number of hits per trial was analyzed to determine, not only how accurately, but how often hits could be achieved under different trial conditions. Significant effects on this variable would reflect both aiming accuracy and the number of shots fired under various trial conditions. A list of significant results and mean number of hits for each of the 192 trial conditions are given in Tables 25 and 26, respectively. With the multiplicity of factors affecting this variable, a great many (27) effects exceeding the .05 level of significance were found, including a significant 7-way interaction at the .008 level. Consequently, this discussion will be limited to those effects judged to be interpretable and/or relevant to the objectives of this study.

Grip Angle. The overall effect of grip angle on number of hits for a given trial was negligible. Two significant interactions involving this variable were grip x slack ($p = .016$) and grip x slack x time ($p = .003$). Both effects can be described from the data presented in Table 27. From this we can see that slightly more hits are, on the average, achieved with

Table 27.

Mean Number of Hits for Moderate and Extreme Grip Angles over Long and Short Trigger Pulls for Two and Four Second Target Exposures

	2 seconds		4 seconds	
	Long pull	Short pull	Long pull	Short pull
Moderate	1.87	2.59	4.75	7.60
Extreme	1.89	2.42	4.94	6.54

the extreme angle under long trigger pull conditions, while more are achieved with the moderate grip under short pull conditions. Furthermore, the greatest difference in mean number of hits is found with 4 second trials using

Table 25.

Significant Effects on Number of Hits for Grip (G), Slack (S), Force (F), Hold (H), Range (R), Time (T) and Motion (M)

Source	Sum of Squares*	d.f.	Mean Squares	F	p
S	1561.230	1/15	1561.230	75.32	<.001
F	881.938	1/15	881.938	17.88	<.001
H	167.814	1/15	167.814	8.72	.010
R	7101.797	2/30	3550.898	143.56	<.001
T	10890.191	1/15	10890.191	151.74	<.001
M	678.754	1/15	678.754	71.55	<.001
GxS	99.188	1/15	99.188	7.46	.016
SxF	116.408	1/15	116.408	6.87	.020
SxR	40.057	2/30	20.028	6.71	.004
FxR	57.508	2/30	28.754	4.84	.016
SxT	494.083	1/15	494.083	41.67	<.001
FxT	176.333	1/15	176.333	15.01	.002
HxT	65.333	1/15	65.333	11.52	.005
RxT	1043.509	2/30	521.755	97.14	<.001
SxM	19.380	1/15	19.380	15.97	.002
RxM	49.048	2/30	24.524	3.58	.041
SxFxH	22.345	1/15	22.345	7.70	.015
GxSxT	53.657	1/15	53.657	13.67	.003
SxFxT	32.505	1/15	32.505	6.57	.022
FxRxM	15.301	2/30	7.651	3.73	.036
HxRxM	17.791	2/30	8.896	3.40	.047
GxFxHxT	9.408	1/15	9.408	5.99	.028
SxFxHxT	9.187	1/15	9.187	8.43	.011
GxSxFxRxT	32.110	2/30	16.055	6.42	.005
GxSxHxRxT	20.607	2/30	10.304	4.75	.017
GxSxFxRxM	37.775	2/30	18.888	7.44	.003
GxSxFxHxRxTxM	24.969	2/30	12.484	5.75	.008

*Error sums of squares are not listed.

Table 26.

Mean Number of Hits for Each of the 192 Trial Conditions

Grip Angle	Trigger Slack	Trigger Force	Hand Hold	10 meters 2 sec. Sta.	10 meters 2 sec. Mov.	10 meters 4 sec. Sta.	10 meters 4 sec. Mov.	25 meters 2 sec. Sta.	25 meters 2 sec. Mov.	25 meters 4 sec. Sta.	25 meters 4 sec. Mov.	40 meters 2 sec. Sta.	40 meters 2 sec. Mov.	40 meters 4 sec. Sta.	40 meters 4 sec. Mov.
Mod.	Long	Lt.	1	3.75	3.50	9.56	7.13	2.00	1.63	5.31	4.38	0.94	1.38	3.87	3.00
			2	3.94	3.56	10.50	7.94	2.88	1.69	7.56	4.25	1.63	1.13	3.88	3.94
		Hvy.	1	2.38	2.69	6.13	4.38	0.69	1.00	2.88	1.75	0.38	0.63	1.38	0.56
			2	2.19	2.50	6.56	5.75	1.06	1.13	5.00	3.25	0.81	0.69	3.06	1.69
	Short	Lt.	1	4.13	4.19	9.94	9.13	1.88	1.75	8.50	6.31	1.44	1.25	5.06	3.81
			2	4.00	4.44	12.00	10.50	3.19	2.19	9.69	7.31	2.19	1.50	7.31	4.12
		Hvy.	1	4.27	3.25	11.06	9.50	2.31	2.31	7.50	5.88	1.00	1.93	4.75	3.75
			2	3.94	3.38	12.94	9.19	2.06	2.60	7.75	5.69	1.19	1.19	5.63	5.13
Ext.	Long	Lt.	1	3.69	3.88	9.88	7.31	1.69	1.63	6.1[illegible]	4.13	0.81	1.13	3.19	3.25
			2	4.06	3.63	9.94	8.25	2.00	1.53	6.50	4.63	0.88	1.13	5.19	2.31
		Hvy.	1	2.44	2.13	7.44	5.53	0.94	1.38	3.44	2.31	0.79	0.81	2.31	1.50
			2	3.06	2.33	7.88	5.56	1.50	1.69	4.06	3.13	0.56	1.13	2.69	2.13
	Short	Lt.	1	4.56	3.69	11.63	8.63	2.63	2.25	7.19	4.88	1.00	1.25	4.81	3.75
			2	4.25	4.56	11.56	9.56	2.13	2.25	8.50	6.88	1.69	1.56	6.13	4.06
		Hvy.	1	3.19	3.13	10.44	6.00	2.00	1.31	6.38	5.00	0.81	1.06	4.37	2.69
			2	3.19	3.13	9.44	7.88	2.13	1.06	6.88	4.40	0.94	1.38	4.00	2.13

a short trigger pull, with the moderate grip angle yielding one full hit per trial more than the extreme grip. If these are true effects, it would suggest that the moderate grip is more compatible with the short pull in terms getting off shots than is the extreme grip.

Trigger Slack. The overall effect of trigger slack was highly significant ($p < .001$), favoring the short pull with mean hits per trial averaging 3.36 and 4.79 for long and short pull conditions, respectively. This difference may be attributable to 2 factors: greater aiming stability (as shown earlier to favor the short pull) and greater ease of firing. Both of these would contribute to a greater number of hits for a given trial.

Three of the more highly significant interaction effects also involved trigger slack. A slack x range interaction ($p = .004$) shown in Table 28 suggests that the drop in number of hits with increasing range is greater

Table 28.

Mean Number of Hits for Long and Short Trigger Pulls over Different Target Ranges

	10 meters	25 meters	40 meters
Long pull	5.29	2.93	1.87
Short pull	6.90	4.50	2.97

from 25 to 40 meters for the short pull than for the long pull. This may be attributable to a floor effect; that is, the long pull conditions may have shown an equivalent drop at these ranges had they not been approaching the limit of "0" hits, which limits the decrement in performance.

A similar explanation might apply to the slack x motion interaction ($p = .002$) shown in Table 29. This effect shows mean number of hits decreasing by 0.78 for the long pull with moving targets as compared with a decrease of 1.10 for the short pull.

Table 29.

Mean Number of Hits for Long and Short Trigger Pulls over Stationary and Moving Target Conditions

	Stationary	Moving
Long pull	3.75	2.97
Short pull	5.34	4.24

The clearest demonstration of the "floor" effect occurred with the slack x time interaction ($p < .001$) and is depicted by Table 30. A sub-

Table 30.

Mean Number of Hits for Long and Short Trigger Pulls over Two and Four Second Target Exposure Times

	2 Seconds	4 Seconds
Long pull	1.88	4.84
Short pull	2.50	7.07

stantial difference in mean number of hits is found between long and short trigger pulls with 4 second target exposures, but the difference is considerably less under 2 second conditions. The fact is that 2 second conditions allowed time for a very limited number of shots (hence hits) in general as compared to 4 second trials, so that weapon configuration differences would be limited to within this smaller range.

All three of the interactions mentioned above, then, appear to be reflective of natural limits imposed by the more difficult target conditions. Such factors are probably operative in many of the significant higher order interactions listed in Table 25.

Trigger Pull Force. As was the case with trigger slack, pull force exerted a highly significant overall effect on number of hits ($p < .001$), the light pull producing a mean of 4.51 as compared to 3.54 for the heavy pull. Again, greater aiming stability and greater ease of firing with the light pull probably combined to produce this difference.

The slack x force interaction due to the virtually inoperative heavy pull on the short, "heavy" pull conditions was found to be significant ($p = .02$) for number of hits, as it was for the previously discussed performance measures. As Table 31 shows, a substantial drop in mean number of hits occurs from light

Table 31.

Mean Number of Hits for Long and Short Trigger Pulls over Light and Heavy Trigger Pull Conditions

	Light pull	Heavy pull
Long pull	4.09	2.63
Short pull	5.13	4.45

to heavy pull with the long pull configuration, while the decrease under short pull conditions is comparatively small.

The force x time interaction ($p = .002$) is shown in Table 32. Here

Table 32.

Mean Number of Hits for Light and Heavy Trigger Pulls over Two and Four Second Target Exposure Times

	2 seconds	4 seconds
Light pull	2.49	6.73
Heavy pull	1.90	5.18

again we see the limitations inherent in the 2 second trials diminishing the difference in mean number of hits between light and heavy trigger pulls. Since fewer shots can be fired with <u>any</u> configuration in 2 seconds than in 4, differences in firing rates (hence, hits) will cause mean differences to increase as time to fire increases.

<u>Hold</u>. The 2-hand hold was superior to the 1-hand hold on number of hits ($p = .01$), with overall means of 4.31 and 3.84, respectively. This effect can probably be attributed solely to the demonstrated superiority of the 2-hand hold with respect to aiming steadiness, thus reflecting fewer misses. There is no reason to believe that hold affects number of trigger pulls.

The hold x time interaction ($p = .005$) shown in Table 33 is similar

Table 33.

Mean Number of Hits for One and Two Hand Holds over Two and Four Second Target Exposure Times

	2 second	4 second
1-hand	2.10	5.58
2-hand	2.28	6.33

to those discussed earlier with respect to trigger slack and trigger pull force, with differences in number of hits increasing as more firing time is allowed.

Target Range. The overall effect of target range was easily predictable and highly significant ($p < .001$). Mean number of hits per trial were 6.09, 3.17 and 2.42 for the 10, 25 and 40 meter targets, respectively. As expected, then, more hits were accumulated on closer (larger) targets.

The significant range x time interaction ($p < .001$) is shown in Table 34. This again reflects increasing mean differences with increasing

Table 34.

Mean Number of Hits for Different Target Ranges over Two and Four Second Target Exposure Times

	2 seconds	4 seconds
10 meters	3.47	8.71
25 meters	1.88	5.54
40 meters	1.23	3.62

time to fire between conditions producing different hit rates.

Target Exposure Time. Needless to say, the overall effect of target exposure time was highly significant ($p < .001$), with 4 second trials producing many more hits per trial than 2 second conditions. Overall mean number of hits were 2.19 and 5.74 for 2 and 4 second trials, respectively. Relevant interactions involving target exposure time have been covered in discussions of the effects of other variables.

Target Motion. Stationary targets produced a significantly greater number of hits per trial than did moving targets ($p < .001$), with overall means of 4.55 and 3.61, respectively. This is undoubtedly attributable to the greater aiming variability, particularly along the horizontal dimension, produced by the tracking of horizontally moving targets.

6. Effects of the Independent Variables on Time to First Shot

Time to first shot (from trial onset), expressed throughout this discussion in milliseconds, describes how quickly subjects are able to fire their first shot under specified trial conditions. Table 35 lists all significant effects on this variable, while Table 36 shows mean time to first shot for each of the 192 target conditions.

Grip Angle. This study produced no overall difference in time to first shot attributable to the moderate vs. the extreme grip angle. Furthermore, no interactions involving grip angle exceeded the .01 level of significance. It is concluded, then, that grip angle plays little if any part in determining how soon the first shot is fired during a trial.

Trigger Slack. The overall effect of trigger slack on time to first shot was not found to be significant ($p = .064$), but it should be mentioned that the mean difference, 1139 milliseconds for the long pull vs. 1107 milliseconds for the short pull, might reflect the slight time differential from onset of trigger pull to detonation between the 1/2 inch (long) and 1/32 inch (short) pulls.

No interactions involving trigger slack exceeded the .01 level of significance.

Trigger Pull Force. A slight effect ($p = .032$) was also found for trigger pull force. Although not exceeding the .01 significance level, this difference was in the direction one might expect, with mean times to first shot of 1100 and 1146 milliseconds for the light and heavy pulls, respectively. This would seem to indicate an overall difference of 46 milliseconds in "squeeze" time favoring the light (5 lb.) pull over the heavy (12 lb.) pull force.

Table 35.

Significant Effects on Time to First Shot of Grip (G), Slack (S), Force (F), Hold (H), Range (R), Time (T) and Motion (M)

Source	Sum of Squares*	d. f.	Mean Square	F	p
F	1588808.0	1/15	1588808.0	5.63	.032
R	22060352.0	2/30	11030176.0	64.18	< .001
T	10291446.0	1/15	10291446.0	171.67	< .001
FxH	434697.2	1/15	434697.2	6.29	.025
RxT	403050.6	2/30	403050.6	4.14	.026
SxM	209335.5	1/15	209335.5	6.36	.024
TxM	8210556.0	1/15	8210556.0	42.94	< .001
GxSxM	119393.9	1/15	118393.9	6.03	.027
RxTxM	780638.4	2/30	390319.2	7.70	.003
GxSxFxR	404466.0	2/30	202233.0	5.05	.013

*Error sums of squares not listed.

Table 36.

Mean Time to First Shot (in Milliseconds) for Each of the 192 Trial Conditions

Grip Angle	Trigger Slack	Trigger Force	Hand Hold	10 meters 2 sec. Sta.	10 meters 2 sec. Mov.	10 meters 4 sec. Sta.	10 meters 4 sec. Mov.	25 meters 2 sec. Sta.	25 meters 2 sec. Mov.	25 meters 4 sec. Sta.	25 meters 4 sec. Mov.	40 meters 2 sec. Sta.	40 meters 2 sec. Mov.	40 meters 4 sec. Sta.	40 meters 4 sec. Mov.
Mod.	Long	Lt.	1	896	886	939	1186	1166	964	1120	1167	1303	1117	1384	1265
			2	953	892	904	1161	1138	1026	1126	1102	1159	1028	1255	1262
		Hvy.	1	980	970	1027	1296	1297	1123	1116	128	1260	1194	1298	1442
			2	1116	955	997	1258	1224	1089	1166	1376	1301	1225	1423	1328
	Short	Lt.	1	982	880	982	1198	1261	979	1160	1130	1290	1013	1258	1196
			2	909	894	994	1096	1075	887	1134	1192	1059	995	1211	1162
		Hvy.	1	931	859	939	1098	1064	938	1123	1076	1302	994	1377	1227
			2	1033	904	907	1156	1226	934	1185	1223	1352	1028	1228	1239
Ext.	Long	Lt.	1	925	971	1028	1236	1193	978	1086	1199	1212	1052	1192	1251
			2	848	901	996	1181	1154	1081	1241	1172	1310	1056	1283	1245
		Hvy.	1	1056	908	941	1210	1314	1052	1212	1213	1349	1156	1337	1348
			2	998	1002	926	1199	1223	974	1219	1196	1220	1078	1348	1293
	Short	Lt.	1	941	886	940	1239	1118	1022	1156	1199	1250	1113	1278	1286
			2	920	877	984	1178	1267	1001	1122	1150	1230	1098	1299	1215
		Hvy.	1	1043	880	936	1191	1212	1011	1154	1106	1262	1037	1258	1344
			2	1079	935	1149	1198	1187	1016	1208	1336	1480	1158	1472	1258

It must be recalled, however, that there was apparently no 12 lb. pull force operating in the short pull condition. In this case, the effect of trigger pull force should be reflected in a slack x force interaction effect. While this effect was not significant (p = .187), it does seem, at least partially, to indicate a triggor pull force effect as shown by Table 37.

Table 37.

Mean Time to First Shot in Milliseconds for Long and Short Trigger Pulls over Light and Heavy Pull Conditions

	Light pull	Heavy pull
Long pull	1107	1171
Short pull	1094	1120

For the long pull, time to first shot increases by 64 milliseconds from light to heavy pull force conditions. For the short pull there is a corresponding increase of only 26 milliseconds. It seems clear, then, that the greater part of the overall difference between light and heavy trigger pull force occurs within long pull configurations where the heavy pull was known to be operative.

Hold. The one and two hand holds produced no overall differences in time to first shot. Furthermore, no interactions involving hold exceeded the .01 level of significance. It seems safe to conclude from this that hold is not a significant factor in determining time to first shot.

Target Range. The main effect of target range on time to first shot was highly significant, with 10, 25 and 40 meter targets showing mean times of 1014, 1134 and 1221 milliseconds, respectively. It is clear from this that subjects took more time to zero in on targets at greater simulated distance (hence, smaller target size). This corresponds with the fact that aiming steadiness following the first shot increased as target distance increased.

Both of these findings reflect greater care on the part of subjects in aiming at more distant (smaller) targets, undoubtedly to increase their chances of scoring hits.

One notable interaction involving range was the range x time x motion effect (p = .003) described by Table 38. The effect is most clearly pictured

Table 38.

Mean Time to First Shot in Milliseconds for Different Target Ranges over Two and Four Second Exposure Times for both Stationary and Moving Targets

	Stationary		Moving	
	2 seconds	4 seconds	2 seconds	4 seconds
10 meters	977	974	913	1192
25 meters	1181	1158	1003	1194
40 meters	1271	1305	1074	1261

in Figure 30, which shows a steeper rise in time to first shot for the 10 meter moving target from 2 to 4 second exposure times than is true for 25 and 40 meter moving targets. In fact, the 4 second moving target condition is the only one in which first shot time for the 10 meter target is not clearly faster than that of either of the longer ranges. This can probably be attributed to the fact that 10 meter moving targets under 4 second exposure time conditions are the only ones which initially appear at the extreme edges of the screen. In such cases, subjects may be somewhat delayed in their perception of trial onset. Whether or not this is true, it is certain that the distance traveled by the weapon from "ready" position to the target is greater for this condition. Either or both of these factors would serve to delay time to first shot.

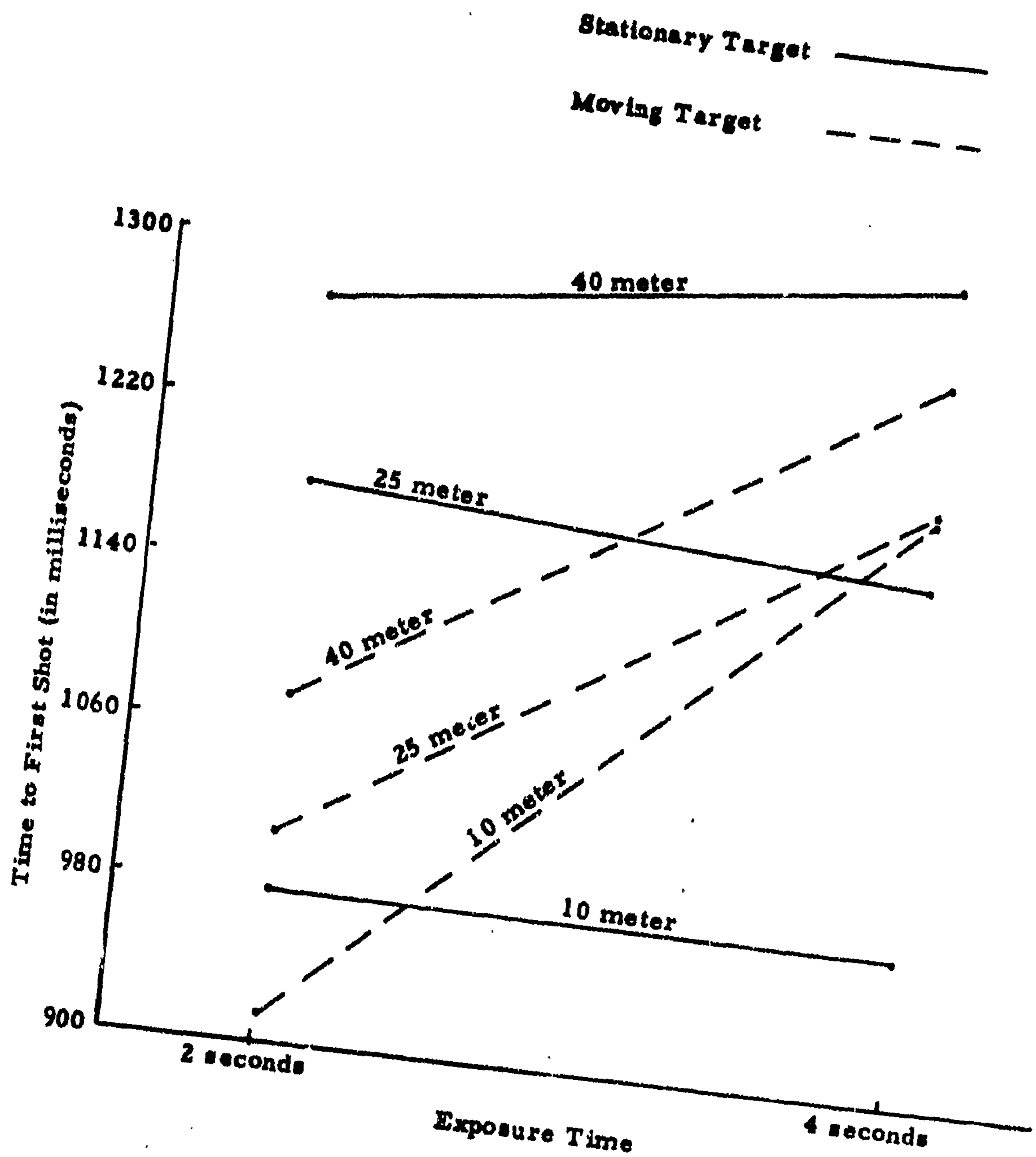

Figure 30. Range x Time x Motion Interaction on Time to First Shot.

Target Exposure Time. Exposure time was a highly significant factor ($p < .001$) in the determination of time to first shot. Overall means for the 2 and 4 second target exposure times were 1065 and 1181 milliseconds, respectively. Clearly, subjects did not hurry their shots as much when 4 seconds were available for firing.

However, we must recall that only under moving target conditions were the subjects aware of how much time was available to them for hitting the target--the distance from target to bar light and target speed allowing them to make such an estimate. With stationary targets there was no clue as to how long the targets would remain available. For this reason, differences in initial shot time between 2 and 4 second conditions would be expected to appear only on moving target trials. The trial x motion interaction ($p < .001$) described by Table 39 shows that this was indeed the case. Virtually all of the

Table 39.

Mean Time to First Shot in Milliseconds for Two and Four Second Trials over Stationary and Moving Target Conditions

	Stationary	Moving
2 seconds	1143	997
4 seconds	1146	1216

difference in time to first shot between 2 and 4 second trial conditions occurs with moving targets. Subjects clearly tended to hurry their first shot when they were aware that only a short time was available for hitting the target.

Target Motion. If the effect of target motion on time to first shot were to be predicted, it would probably be assumed that more time would be taken to fire at moving targets, since motion should add to the difficulty of zeroing in. If anything, mean time to first shot indicates the opposite for this study, with means of 1140 and 1106 milliseconds for stationary and moving targets, respectively. This difference ($p = .076$) approaches, but does not achieve statistical significance at the .05 level. Part of the reason for this apparent reversal of the expected effect was alluded to in the discussion of target exposure time. Table 39 reflected the fact that only under moving target conditions were subjects able to judge trials as being 2 or 4 seconds in duration, and tended to rush their first shot only for 2 second, moving target conditions. It is interesting to note that with stationary trials, where trial duration could not be determined, mean times to first shot were substantially longer than for the 2 second, moving target trials. Rather than taking a "safe" approach and assuming 2 second durations for stationary trials, subjects apparently assumed the optimistic position that targets would remain long enough to be aimed at and hit. This is also reflected in the fact that the majority (12 out of 17) of trials in which subjects failed to fire a shot were 2 second, stationary target conditions.

VII. SUMMARY AND CONCLUSIONS

A. Summary of Results and their Implications

A capsule summary of what are considered to be the major results is presented in Table 40. Scanning the row labeled "Grip Angle", it can be seen that the effect of this variable on our performance measures was generally negligible, with the possible exception of horizontal aim dispersion, the moderate grip angle showing somewhat greater horizontal aiming steadiness than did its more extreme counterpart. The extreme grip angle as defined for this study is similar to that of the Luger. That is not to say, however, that the total grip configuration is equivalent to the Luger grip. The similarity in this case is only concerned with the acute angle formed by the forward edge of the grip and a line perpendicular to the center line of the barrel. The angle formed by the rear edge of the extreme grip was, in the study, equivalent to that of the basic configuration of the Caliber .45 Automatic Pistol M1911A1, resulting in a grip with a smaller circumference than that of either the standard .45 or the real Luger. This fact is mentioned here, since, in our earlier discussion of the apparent superiority of the moderate grip angle on horizontal steadiness, it was suggested that the relative "thinness" of the extreme grip may have produced less horizontal stability. If such is the case, we would not expect the same effect to occur with a totally simulated Luger grip, which would have a greater circumference.

The effect of trigger slack, as Table 40 shows, was significant on all performance measures except time to first shot, reflecting in each case the superiority of the short pull. The .03 inch trigger pull produced greater overall aiming steadiness, a higher percentage of hits and a greater number of hits per trial than did the .8 inch pull. There was also a trend-- while not quite achieving statistical significance -- favoring the short

Table 40.

Descriptive Summary of Major Results on Each Performance Measure

Independent Variables	Horizontal Aim Dispersion	Vertical Aim Dispersion	Percent Hits	Number of Hits	Time to First Shot
Grip Angle	. Moderate grip superior . Most noticeable with long light pull on moving targets	. No statistical difference	. No statistical difference . Does not affect constant aim error	. Main effect negligible	. No significant difference
Trigger Slack	. Short pull superior . Short pull tends to be steadier after first 2 sec.	. Short pull superior	. Short pull superior	. Short pull superior	. No significant difference (trend favors short pull)
Trigger Pull Force	. Light pull superior . Heavy pull <u>not</u> adequately tested with short trigger slack	. Light pull superior	. No statistical difference (trend favors light pull)	. Light pull superior	. Marginally significant favoring light pull .
Hold	. 2-hand superior	. 2-hand superior	. 2-hand superior	. 2-hand superior	. No significant difference
Target Range	. Aiming precision increases with target range	. Aiming precision increases with target range	. Higher % hits on closer ranges	. More hits at close range	. First shot quicker the closer the range
Target Exposure Time	. Aiming precision increases somewhat with greater exposure time	. No main effect	. Percent hits increases with exposure time	. Number of hits increases with exposure time (4 sec times yield 2.7 times more hits than 2 sec times)	. When exposure time is known, first shots are quicker for short duration exposures
Target Motion	. Greater precision with stationary targets . Most noticeable for 10 meter targets	. Greater precision with stationary targets . Effect not as marked as Horiz. Dispersion	. Stationary targets yield higher % hits	. Stationary targets yield more hits	. Motion by time interaction favoring 2 second moving targets

pull on time to first shot. Clearly, then, the short trigger pull is superior, perhaps in every respect, to the long pull with this particular type of weapon. It is not certain from these results, however, whether this would hold for weapons with different basic configurations; for example, weapons having triggers with a greater finger contact surface or a different center of gravity. Also, the slack distances compared in this study were extreme. It may be that certain advantages would appear with intermediate trigger pull lengths -- falling somewhere between the .03 inches and .48 inches tested in this study.

The light (5 lb.) trigger pull was also found generally superior to the heavy (12 lb.) pull in aiming steadiness, number of hits and, to a lesser degree, percent hits and time to first shot. As mentioned earlier, these overall differences were probably attenuated by the fact that the short, "heavy" pull trigger assembly, in fact, was similar to the short, light pull, at least by the end of the study. Therefore, it must be concluded that the effect of trigger pull force under short (.03 inch) pull conditions was not adequately tested. Furthermore, as was mentioned with respect to trigger slack, it cannot be automatically assumed that the effects of pull force found in this study would necessarily hold for weapons having characteristics other than those found in the basic test weapon used for this investigation.

The 2-hand hold was clearly superior to the 1-hand hold in aiming steadiness and shot accuracy, although it did not affect time to first shot. This hold appears to be the best, then, particularly when accuracy is paramount. For quick, close-up confrontation situations, however, the 1-hand hold might be equally efficacious.

Target range affected all performance measures significantly. Closer (larger) targets, while promoting greater aim dispersion, were hit more frequently, a greater percentage of the time, and were shot at more quickly. Since aim dispersion was a much less significant factor in determining hits for large targets, it can be said that weapon variables affecting aim dispersion assume less importance in close confrontation situations.

Longer target exposure time tended to increase slightly the overall aiming and shooting efficiency of subjects in this study. Time to first shot results indicated that subjects tended to rush their first shots when they were aware that targets would remain for only a short (2 second) duration.

Target motion greatly increased the magnitude of aiming dispersion, particularly the horizontal, the dimension along which targets move, thereby decreasing percent and number of hits per trial. This increase was particularly noticeable for the 10 meter target, whose "real" motion was considerably faster than target movement at longer ranges. Time to first shot was quicker for 2 second moving targets, and slower for 4 second conditions as opposed to no difference between 2 and 4 second stationary targets. This can be attributed to the fact that only under moving target conditions were subjects able to estimate target exposure time.

B. Conclusions

From the results summarized above (and in Table 40) it is evident that for the Caliber .45 Automatic Pistol M1911A1, the short, light trigger pull with a moderate (standard) grip angle was generally superior to other configurations represented in this study. As it happens, this combination represents the standard .45 pistol as currently manufactured. Therefore, no recommendations for change on the variables tested can be made for this particular weapon.

C. Directions for Future Study

Since this study dealt with only two levels of each of the three weapon configuration variables tested, performance curves on these variables could not be generated. Taking trigger slack as an example, it might be assumed that the difference in aim dispersion found between long and short trigger pulls represents a linear increase in dispersion from .03 to .48 inch pull distances. Since no intermediate slack distances were employed, however, such a conclusion at this time represents no more than a guess. It may be desirable, then, to employ intermediate slack distances in future studies to determine the true nature of this function. The same is true regarding the superiority of the 5 lb. trigger pull force over the 12 lb. pull. If this main effect of pull force is linear, it would suggest reducing pull force to even less than the 5 lb. force currently employed. On the other hand, if the function is non-linear, an as yet untested pull force might prove to be optimal. Again, only further research on different levels of the pull force dimension can resolve this question conclusively.

Further study would also be necessary to determine the true relationship between slack and pull force, since the short, heavy pull condition was not adequately represented in this study. It may be that a 12 lb. pull force is, in fact, not significantly inferior to the 5 lb. pull with a pull distance of only .03 inches. Studies might be designed to confirm or reject this possibility, and also to determine optimal slack-force combinations.

It has not been conclusively shown that the trigger slack, pull force and grip angle levels found to be superior in this study would be equally so for other styles of handguns. For example, the Luger, a weapon generally held in high regard, has a more extreme grip angle, longer trigger slack and greater pull force than the standard .45. Nevertheless, it is thought by many to be a more efficient weapon.

As noted earlier, its grip angle at the front edge of the grip is similar to that of the extreme grip angle employed in this study, which proved to be inferior, if anything, to the standard .45 grip with respect to horizontal aiming accuracy. The Luger, however, also has a more extreme angle at the rear surface of the grip, thereby giving its grip a greater circumference than that of the test weapon in its extreme grip configuration. If, as suggested earlier, circumference, rather than grip angle, was responsible for the apparent inferiority in horizontal steadiness, the effect would not hold for the actual Luger grip.

While trigger pull force for the typical Luger is in the neighborhood of 12 lbs., the "feel" is that of a much lesser force when compared to that of our test weapon. One reason for this is the design of the trigger itself, which is, for one thing, wider than that of the .45, allowing force to be distributed over a greater surface of the finger. This, along with other features of the trigger design, might obviate the undesirable effect of the heavy pull on aiming accuracy found in this study.

Another difference between the Luger and the .45 concerns the location of the center of gravity (CG) for each weapon. The CG of the Luger is more toward the rear of the weapon, which feels as though it is balanced on the top of the hand. The possibility exists that this "rearward" CG might considerably dampen the deleterious effect of longer trigger slack on aim dispersion which was found in our study. Typical trigger slack distance for the Luger is in the neighborhood of 1/8 inch, discriminably greater than the .03 inches used for our short pull.

It may be, of course, anecdotal information notwithstanding, that the Luger configuration is actually inferior in accuracy for reasons involving its slack, pull force and grip angle. If more hits are actually scored in the field with this weapon than with the .45, it may be attributable to the overriding effect of differences in recoil or other factors not tested in this study. In any case, further laboratory studies could be designed to settle these questions or those raised by comparison of the .45 design with that of any other type of pistol.

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APPENDIX 1

Description of Equipment

A. Introduction

The purpose of this Appendix is to provide detailed information concerning the equipment used in this study. The material here is organized along the same lines as Chapter IV. C., in that various subsystems (assemblies) of equipment are treated here separately. The content is primarily factual and contains descriptions and photographs of the equipment and in the case of manufactured items, nomenclature is provided. On occasion, where a design rationale seems appropriate, it is also given.

B. PDW Test Weapon(s)

1. Designed and fabricated by the Bellmore-Johnson Tool Company, Hamden, Connecticut.

2. Basic configuration resembles the Caliber .45 Automatic Pistol M1911A1. The test weapon shoots a continuous beam of IR light (nonvisible spectrum) from the time the power is turned on to the time power is shut off. In other words, the trigger does not control the light beam. The IR beam is produced by a small arc lamp filtered through an IR pass filter. The IR beam is focused to a spot size of 0.08 inches in diameter which in the context of this experiment is 0.67 mils. When the spot is recorded photographically, it appears as either a short trace or a "roundish" spot depending

upon the amount of weapon movement at the instant of recording. The test weapon does not fire a projectile nor does it produce either recoil or an auditory report to simulate an actual weapon. However, in order to provide the shooter with a signal that he has "fired," an auditory "pop" is generated by a Dynakit Mark III amplifier each time the trigger is pulled. This "pop" is easily detectable but in no way approaches the loudness of a weapon report.

The test weapons function similarly to real weapons. For example, to successfully fire the test weapon, the subject must hold it properly so the grip safety will function; further, the subject must fully release the trigger after "firing," as is the case with the M1911A1, or the device will not fire again.

The detailed description of the test weapon characteristics and its subassemblies is given below.

- Overall dimensions are identical to the M1911A1, except in the length of the "barrel."
- Weight is approximately 2.5 pounds and almost the same as a loaded M1911A1 weapon.
- The balance and center of gravity of the test weapons are almost identical to the M1911A1.
- Figure 31 shows the major subassemblies of the experimental PDW.

3. <u>Barrel and Lens Assembly</u> (including the slide)

- Overall length 14-3/4 inches
- Arc Lamps
    - Sylvania Concentrated Arc Lamps
        - 2-Watt Tungsten and Zirconium

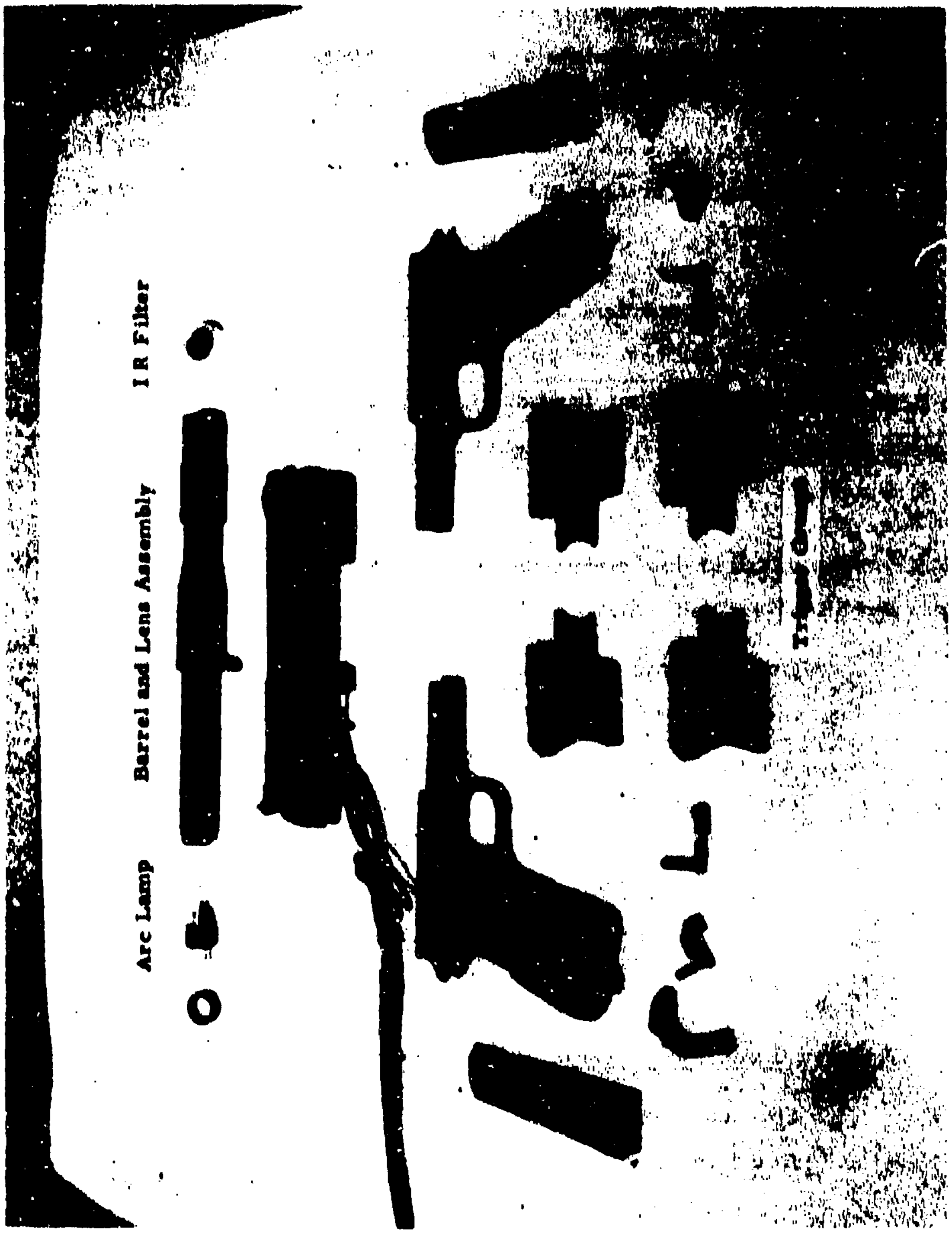


Figure 31. View of the Major Subassemblies of the Experimental PDW

- Power Supply for Arc Lamp, manufactured by G. W. Gates and Company, Long Island, New York.
- Lens Assembly
  - Length 2.5 inches (at the muzzle)
    - -- Adjustable focus with locking ring.
  - Lenses
    - -- Diameter(s) 19 mm
    - -- Front, converging Achromat, FL 92 mm
    - -- Rear, diverging Achromat, FL -30 mm
- Infra-red filter at the muzzle (used for experimentation)
  - 89B-IR visual opaque Wratten Gelatin Filter (Kodak)
- Training filter at the muzzle
  - #52 green Wratten Gelatin Filter (Kodak)
- Training Goggles
  - American Optical Company
  - Variable Density No. 74-G-79-40 with red plastic visor.

4. <u>Sight System</u>

- Sight Radius 7 inches
- Front Sight is the square front type
- Rear Sight
  - Adjustable for range and windage
  - Type of sight - Smith and Wesson - type used on the S&W K series revolver with a square notch
- The sight rib is parallel and concentric with the barrel and lens assembly and are dove-tailed together by the barrel bushing at the front end of the slide (tolerance - ± .001 inches).

5. <u>Slide</u>

- Length 7.69 inches

6. Frame

- Two standard M1911A1 frames were purchased.
- The grip angle of one frame was modified to simulate the grip angle of a Luger. This modification plus the unmodified frame provides the capability of two grip angles for the PDW Test Weapon.
- Grip Angles are defined as the acute angle formed by the forward edge of the grip and a line perpendicular to the center line of the barrel.
  - The values of the Grip angles are:

    Moderate Grip Angle 17.5° (M1911A1)

    Extreme Grip Angle 30° (Luger)
- The interchange of grips can be accomplished in less than 2 minutes.
- Cable providing power to the test weapon is inserted through the lower end of the grip where the magazine is inserted in a normal weapon.

7. Trigger Group

- All combinations of two levels of trigger slack and trigger pull force are provided through four trigger group assemblies.
- The values of these variables are:

Trigger slack	.03 inches and .48 inches
Trigger pull force	5 pounds and 12 pounds

- The trigger group assemblies are designed to facilitate interchange in a short period of time--less than 2 minutes.

8. Materials

The materials used in the fabrication of the PDW Test Weapon include:

- Standard M1911A1 frames
- Trigger Group assemblies consist primarily of steel parts
- Barrel is made of aluminum and both the inside and outside diameters are anodized black.
- Slide is fabricated from phenolic filled linen. This material was selected because of its resistance to changes in temperature and humidity and because it can be accurately machined.

9. Tolerance

In general, standard "gun" tolerances were employed in the fabrication of the weapon, and surface finishes were a minimum of 32 RMS smoothness. In some cases where accuracy was critical, such as the interrelationship between the sights and the lens assembly, tolerances of .001 inches were employed. In other cases tolerances of .003 inches were utilized.

C. Stimulus Presentation Subsystem

1. General

Stimuli or targets are presented by projecting them on a curved screen with a slide projector. Target movement is obtained by mounting the slide projector on a motor driven turntable. Three different target slides were used to simulate target ranges of 10, 25, and 40 meters. The targets were similar to the standard silhouette E targets, differing only in that the curved edges (rounded corners) of the E targets were eliminated and "square" corners were substituted. However, overall target dimensions and proportions were maintained. A Control Unit, to be described in paragraph E of this Appendix, controls the various stimulus presentation functions such as target exposure time and speeds of moving targets, etc. The turntable and slide projector are mounted on a stand which is bolted to the floor. As part of this subsystem, there is also a "Shooting Table" on which are mounted a pair of "Bar Light" projectors. The primary function of the Shooting Table is to hide the slide projector and turntable position from the view of the test subjects to prevent them receiving any cues as to the nature of the trial they are about to perform. A curtain, located on the subject's side of the Table, prevents him from looking under the table and receiving cues in that manner. The table also serves as a mount for the "Bar Light" projectors and as a place to lay the test weapon between trials. The "Bar Light" projectors are used only during trials in which there is a moving target. Their only function is to project a vertical bar of light approximately 3/4 inches wide and 30 inches high at the screen. The bar of light indicates, to the subject, the terminal position of the moving target. When the leading edge of the moving target touches the bar of light, the target and bar of light are extinguished. Thus, the bar of light simulates a point of cover to which the target is "running." Only the bar of light representing the target's terminal position is visible on a given trial. The Bar Light projector is positioned manually prior to a trial in a predesignated position. Light weight cardboard hoods hide the position of the projectors from the subject to prevent their acquisition on trial cues.

The following paragraphs specify the pertinent details of the several components of the Stimulus Presentation Subsystem.

2. Turntable

The Turntable is best described by Figure 9. It consists of two heavy aluminum plates, a ball bearing race, a small electric motor and a potentiometer (not visible in Figure 9). The lower plate is semicircular and has a thin, hard rubber semicircular track for the drive motor to run over. The ball bearing race is mounted on the lower plate. The upper plate rides on the ball bearing race and is cantilevered forward from the center of rotation of the ball bearing race. The motor and potentiometer are mounted on the upper plate. As can be seen in Figure 9 (center), the motor is "suspended" from the upper plate so that its drive shaft rides on the rubber track on the lower plate. Thus, as the motor's drive shaft travels around the track, the upper plate moves with the motor. Two idler wheels, mounted from the upper plate, ride on the lower plate and prevent binding caused by the upper plate and the cantilever design. The potentiometer provides the control unit with continuous information as to the position of the Turntable.

The nomenclature of the Turntable motor and potentiometer are:

- Motor - 12 volts DC, Model No. TRW 5A540-4
- Potentiometer

3. Slide Projector

- Kodak Ektagraphic RA-960
- Lens - Kodak projection EKTANAR LENS (5 inch) f/3.5
- Mounted such that the center of the lens is:
  - 31.25 inches above the floor
  - 99.75 inches (horizontal) from the projection screen
  - Angle of elevation 13.75° above the horizontal
  - The long axis of lens is coincided with the Turntable radius.

4. Target Slides

- E type silhouette - modified (see background of Figure 10)
- Target slides are designed to correct for distortion at the screen due to the 13.75° projector angle

- Height of target images at the screen
  - 40 meters, 3.05 inches
  - 25 meters, 4.88 inches
  - 10 meters, 12.19 inches
- Height of top of target above the floor
  - 40 meters, 63.10 inches
  - 25 meters, 61.95 inches
  - 10 meters, 57.38 inches

  Based on eye height of 65 inches
- Filter over target slides - Kodak Wratten Gelatin Filter #52.

5. <u>Bar Light Projectors (2)</u>

- Located on the right and left ends of the Shooting Table
- Taylor Merchant Micro Projector
  - Model 300, 100 Watts, with Model A aperture adapter
  - Lens: TMC Rohar Micro Lens 1:2.8, f= 60 mm
- Filter over Bar Light Slide - Kodak Wratten Gelatin Filter #52

6. <u>Shooting Table</u>

- See Figure 10 for configuration
- Height of top surface 42.75 inches
- Dimensions
  - 15.5 inches x 72 inches
  - Radius of curved portion 33 inches

7. <u>Projection Screen</u>

- Beaded Screen 8 feet x 21 feet
- Mounting frame - Manufacturer Nick Mulone and Son, Cheswick, Pennsylvania
  - Radius or curvature 9 feet 6 inches
  - Arc of curvature 127 degrees
- Screen mounted to frame with tension springs.

D. Data Recording Subsystem

1. General

Data recording is accomplished through the means of a movie camera with IR sensitive film and a timer/printer to record the time of each trigger pull. The movie camera is mounted on the Turntable beside the slide projector (see Figure 9) and aimed to photograph the area of the screen covered by the slide projector. The juxtapositions of the camera and slide projector remain constant throughout all conditions.

To aid in correlating the timer/printer records with the film record, a "Shot Pulse" LED was utilized. From Figure 9, it can be seen that the LED is mounted on a boom in front of the camera and in the camera's field of view. The LED looks at the camera. The LED emits IR light. When the trigger is pulled, the LED emits its light for a period of 0.04 seconds. This produces a large black "cannonball" (shot pulse) in the lower right corner of the film frame in which the trigger was pulled. Figure 12 shows the nature and location of the cannonball (shot pulse) as it appears to the film analyst. The shot pulse clearly identifies the frame associated with the trigger pull. The duration of the LED's "on" time is long enough to assure that it will span the time gap between successive film frames. Also, the shot pulse duration is short enough that it might appear on two successive frames but never on three.

For convenience and speed of running test trials, two movie cameras were employed. The following paragraphs specify the pertinent details of this subsystem's components.

2. Cameras (2)

- Paillar Bolex 16 mm
- Model H 16S
- Frame speed set at 20 frames/second

- Lens
  - Lytar Som Berthiot (1:1.8 F = 25 N21215)
  - F stop set at 1.8
  - Focal distance setting 9 feet
- Mounted such that camera lens is:
  - 36.75 inches above the floor
  - 99.25 inches (horizontal) from the projection screen
  - Angle of elevation 10 degrees above the horizontal
  - 7.5 inches to the right of the projector lens
- Filter - Kodak Wratten Filter #25
- Film - Kodak high speed infrared film 2481 (black and white)
  - Estar base for 16 mm High Speed Camera (125 feet/roll)
  - Eastman Kodak, Rochester, New York
- Power Supply for Camera
  - Model 865B: 0-40 volts, 2 amps, Harrison Laboratories, Inc., Berkley Heights, New Jersey

3. Timer/Printer (Figure 32)

- Digital Printer - Model 610, 1 amp, 115 volts, Newport Laboratories

4. Light Emitting Diode (LED)

- Monsanto ME2 (Infrared)

E. Control Unit Subsystem

1. General

The overall control of test trials, including stimuli presentation and data recording, is accomplished through three items of equipment located on the Experimenter's Control Desk. These items are the Master Control Unit, the Target Speed Regulator and the Target Selector (see Figure 11).

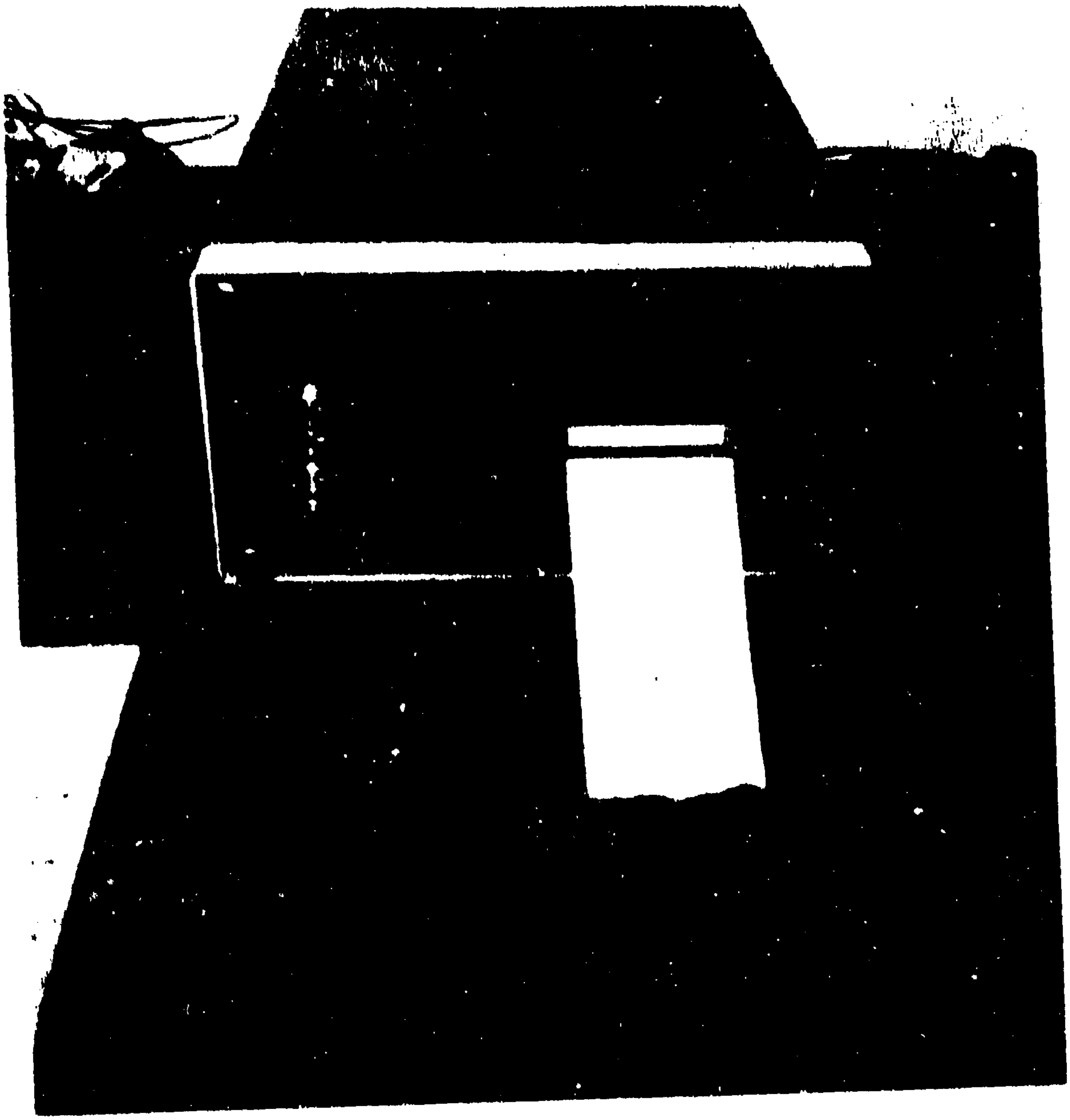


Figure 32. Time Counter and Printer (Detail)

The Target Selector is simply a remote control unit for the slide projector and its carousel and permits the remote selection of the desired target slide. The Target Speed Regulator is a powerstat variable auto transformer and controls the motor that drives the Turntable. Because we are simulating three target ranges on the screen, three different speed or power settings are necessary, one for each target range.

The Master Control Unit (see Figure 33) contains eight controls and provides seven functions. Referring to Figure 33 and beginning on the left of the panel, the functions are described below.

a. The toggle switch on lower left of the panel is the panel's power ON/OFF switch.

b. The clock-like control is a potentiometer and controls the target's initial position on the screen. That is, this control makes it possible to move the Turntable and, consequently, the slide projector to a predetermined position where the target will appear at the desired location on the screen.

c. The toggle switch labeled "Time 2-4 sec" is a two-position switch and determines the duration of a trial.

d. The Start button activates a test trial.

e. The Reset button enables the Turntable to be repositioned following the completion of a trial and prior to the next trial.

f. The "Motion" switch is a two-position toggle switch to select either a stationary target condition or one in which the target is moving.

g. The "Range" control is nonfunctional. The Target Selector and Target Speed Regulator have replaced this control.

h. The "Direction" switch is a two-position toggle switch which determines the direction a moving target will move--to the right or left.

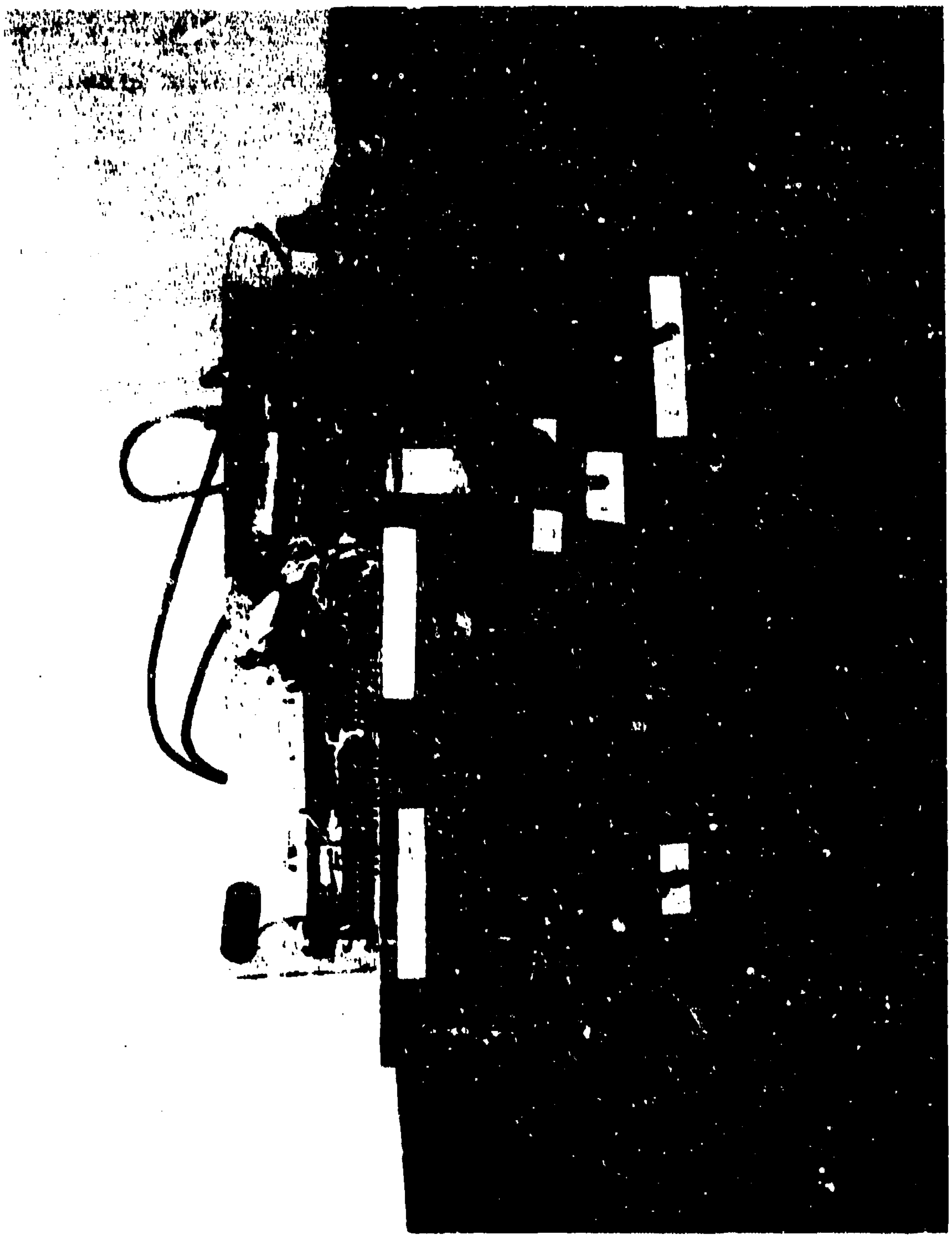


Figure 33. Master Control Unit (Detail)

A functional block diagram of the entire system of equipment used to present stimuli and record data is shown in Figure 34. The following paragraphs specify the nomenclature of the subsystem components.

2. Target Selector

- Kodak Carousel RA-950, Remote Control

3. Target Speed Regulator

- Powerstat variable auto transformer, Superior Electric Company, Bristol, Connecticut
- Type 3PN 1168
- In volts 120, Out volts 0-140, A-10
- KVA 1.4

4. Master Control Unit

- Designed and built by Reflectone, Inc., Stamford, Connecticut
- Power supply
  - 32 volt, 2.5 amp
  - Model HY-Z1-32-2.5, Hyperion Industries, Watertown, Massachusetts

F. Data Reduction Subsystem

1. General

The raw data collected during the experiment were recorded on 16 mm movie film, and the paper tape produced by the timer/printer. These data had to be correlated, reduced and somehow arranged in a manageable form for statistical analysis. By employing a 16 mm data analysis projector and a "sonic digitizer" (supplied by U. S. Army HEL), the raw data from the movie film were "automatically" and directly stored

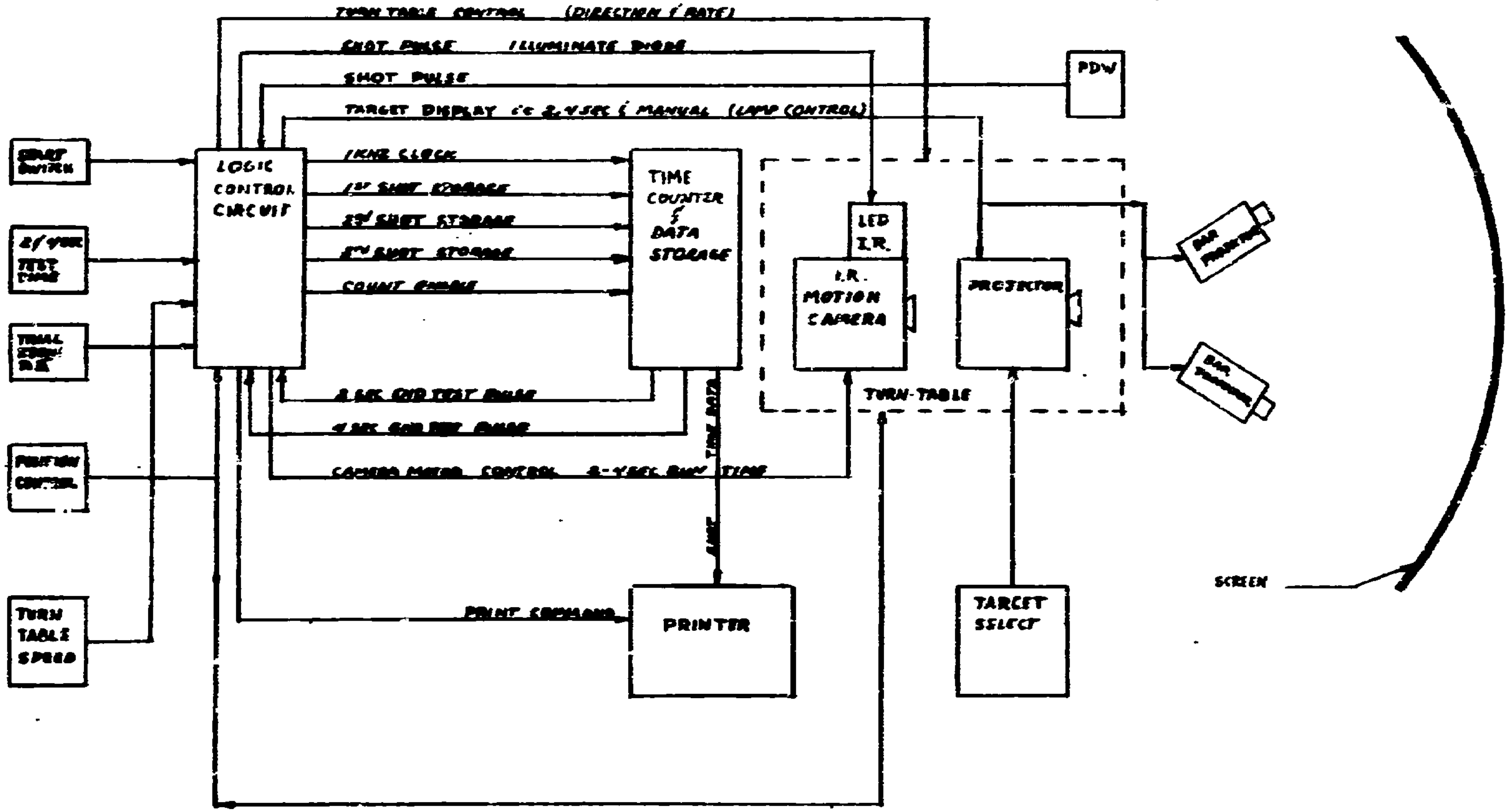


Figure 34. PDW System Functional Block Diagram

on punched paper tape produced by the sonic digitizer's teletypewriter. Data from the timer/printer were manually correlated and inserted on the punched paper tape by means of the teletypewriter. The raw data, on the punched paper tape, were ready for further reduction and statistical analysis by a computer.

The following paragraphs specify nomenclature of the equipment comprising this subsystem.

2. <u>Analysis Projector</u>

- LW Photo Optical Data Analyzer Model 224-A, 16 mm.
  - LW Photo, Inc., Van Nuys, California
- Lens -- 2-inch Kodak projection EKTANAR lens, F 1.6
- Mounted such that projector lens is:
  - 20 inches above the center of the frame image
  - 99.25 inches from the digitizer screen
  - 7.5 inches left off-set from center of frame image
  - Angle of depression 10 degrees below the horizontal

    NOTE: This compensates for distortions introduced on the film due to the way the camera was mounted on the Turntable.

3. <u>Sonic Digitizer (Supplied by U. S. Army HEL)</u>

- Digitizer Screen, Serial No. 7379
  - Resolution -- 55 units/inch
- Omnitec Telephone Coupler
- Data Link Coupler, Model 1624
- Graf/Pen Sonic Digitizer, Model GP-2
- Stylus
- Teletypewriter, Model 33, equipped with
  - Punch and reader for 1-inch paper tape data storage.

G. Trial Identification Materials

1. General

A system of identification slides was developed and used to clearly distinguish between test trials recorded on film. With these slides each test trial could be associated with the subject who performed the trial. Before beginning a trial, appropriate ID slides were displayed on the screen and photographed with the movie camera. Therefore, the record films contain both the trial ID and the trial performance. The following is a list of type and number of various ID slides that were used:

Subject Code	A - P (16)
Session Code	1 - 16 (16)
Trial Code	1 - 12 (12)
Trial Abort	Abort (1)

The ID slides were stored in the projector's carousel and selected by the Target Selection unit. A push button switch was used to activate both the slide projector and the movie camera simultaneously.

H. Visual Choice Reaction Time Apparatus

1. General

As part of the screening of subjects, candidates had to perform visual choice RT tasks. Figure 14 shows the equipment used for screening subjects. The apparatus functions as follows: when the experimenter depresses one button on the stimulus select unit, a small light on the response unit opposite the corresponding button is illuminated. Simultaneously, the timer starts. The subject's task is to extinguish the light as rapidly as possible by depressing the button associated spatially with the light. When the correct button is depressed, the timer stops.

I. Calibration Apparatus

1. General

Two types of calibration functions were conducted routinely during the experiments. Prior to each period of testing, the zero of the test weapon was checked and, when necessary, the sights were adjusted appropriately. Zeroing was accomplished by mounting the test weapon on a bench rest, which in turn was mounted on a heavy-duty surveyor's tripod. The azimuth and elevation of the weapon could be adjusted with cranks on the tripod. A calibration target was placed on a wall, 8 feet in front of the weapon's muzzle, and used as the aiming point (see Figure 35). The procedure involved removing the IR filter from the weapon muzzle and placing the weapon on the bench rest. Then, using the hand cranks on the tripod, the light spot was positioned squarely on the cross hairs of the calibration target, within the small circle. Finally, appropriate adjustments in elevation and windage were made with the rear sight until a perfect sight picture was obtained with the target's large circle "sitting" on top of the front sight and properly aligned with the rear sight.

Muzzle calibration (grooving) took place immediately prior to every test trial. The procedure for this calibration has been described in Chapter V, B. 5. The materials and equipment used in this procedure included a 35 mm camera mounted on a tripod, the position of which was fixed, and a muzzle calibration chart mounted on the wall opposite the camera. Also used in conjunction with the calibration chart was a small piece of cardboard on which was drawn a "bracket" representing the acceptable size of the envelope for the muzzle location. The bracket represented a 4-inch envelope at the muzzle. The bracket card could be moved from one location to another on the calibration chart to correspond

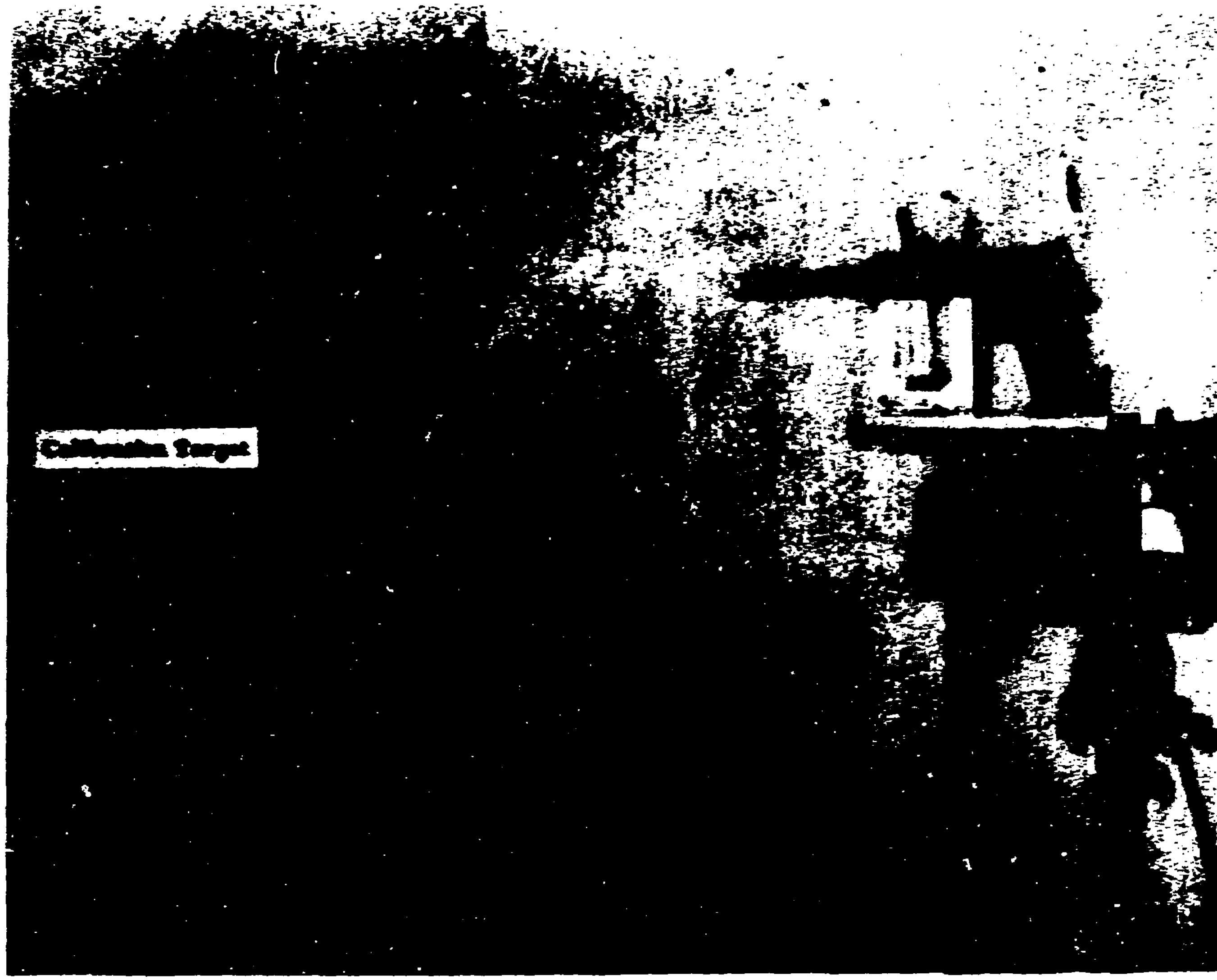


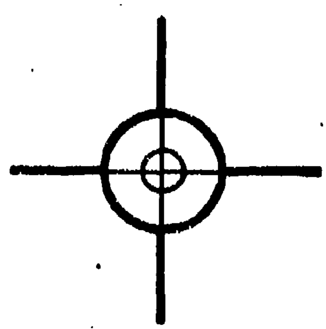
Figure 35. PDW Mounted on Bench Rest for Calibration

with the location of any subject's envelope. While not necessary, the bracket card was a convenience to the experimenter and facilitated the procedure.

The following paragraphs list equipment and material employed to accomplish the several calibration activities.

2. Weapon Calibration (Zeroing)

- Bench rest (see Figure 36)
    - Designed and fabricated by Bellmore-Johnson Tool Company, Hamden, Connecticut
- Heavy-Duty Surveyor's Tripod (nondescript)
- Calibration Target
    - Design (see sketch below)
    - Large circle O.D. = .70 inches
    - Small circle O.D. = .25 inches
    - NOTE: Diameter of Large Circle determined emperically and represents the maximum vertical adjustment of the rear sight at a range of 8 feet from the muzzle. The diameter of the Small Circle is arbitrary and is approximately equivalent to 2 mils at 8 feet.



Sketch of Calibration Target

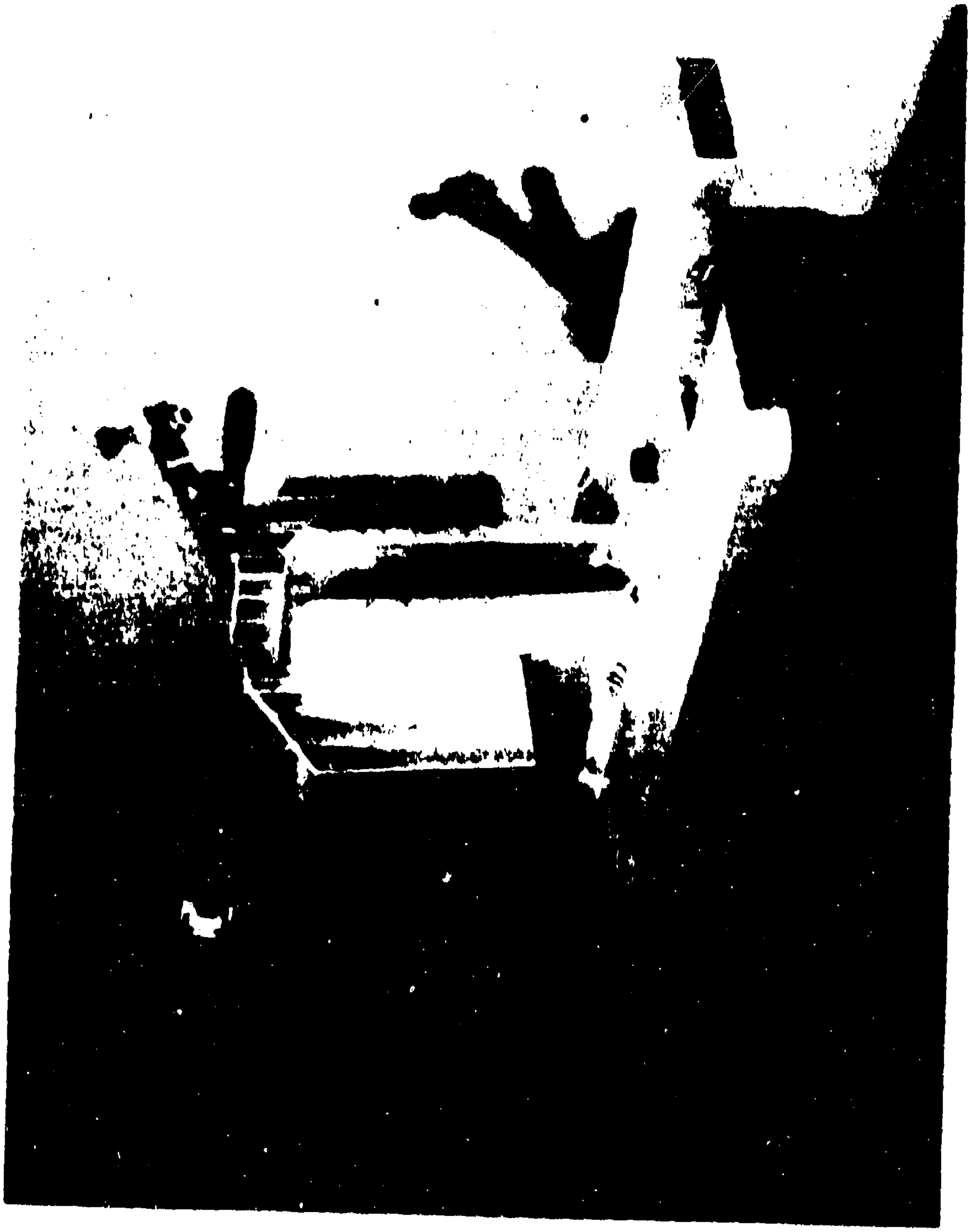


Figure 36. Bench Rest (Detail)

3. <u>Muzzle Calibration</u>

- 35 mm Camera (nondescript)
- Photographer's Tripod (nondescript)
- Muzzle Calibration Chart, designed so that the distance between the vertical lines was equivalent to 1 inch of horizontal distance at the test weapon's position (see Figure 21).
- Envelope Bracket Card, designed so that the bracket was equivalent to 4 inches of horizontal distance at the test weapon's position. Masking tape was used to fix the position of the card to the Muzzle Calibration Chart.

APPENDIX 2

Outline of Screening and Orientation Procedures for Subjects

A. <u>Introduce Ourselves to Subjects</u>

1. Review Payment Agreement and Arrangements

B. <u>Screening Procedures</u>

1. Vision Test
   - Test Subject's Visual Acuity
2. Perceptual Motor Test
   - Test Subjects Reaction Time
3. Subjects Fill Out Personal Data Form
4. Obtain Physical Measurements of Subjects
   - Height } with shoes and clothing
   - Weight }
   - Hand Measures
     - Length
     - Breadth

C. <u>Orientation</u>

1. Background
   - Soldiers have difficulties hitting targets with the Caliber .45 M1911A1 Automatic Pistol.
   - A need to supply personnel who, because of their duties cannot or do not normally carry a rifle, with a PDW with which to protect themselves in close combat situations. A PDW is a defensive not an offensive weapon.
2. Purpose of the Study
   - To collect some basic information about how weapon and target characteristics affect the ability of a shooter to hit targets.
   - This is the first of a number of studies to be conducted on this topic.

3. **Objective of this Study**

- **To Determine How Aiming Accuracy is Affected By:**
  - **Target Size (Range)**
  - **Target Presentation Characteristics (Moving/Stationary)**
  - **Weapon Configuration**
    - .. **Grip Angle**
    - .. **Trigger Pull Force**
    - .. **Trigger Slack**
  - **Human Performance Requirements**
    - .. **Time to Fire**
    - .. **Hand Grip (One Hand vs. Two Hand)**
    - .. **Shooter Position (Standing)**

4. **Demonstrate Test Apparatus**

- **Pistol**
  - **Configurations**
    - .. **Two Grip Angles**
    - .. **Four Trigger Assemblies**
  - **Light Spot**
    - .. **With and Without Filter**
- **Moving Target**
  - **One Condition (2 second, 10 meter)**
    - .. **Call Attention to Bar Light**
- **Show**
  - **Traverse Assembly**
  - **Camera**
  - **Projector**
- **Show Subjects Sample of the Filmed Data**

APPENDIX 3

Instructions for the Visual Choice Reaction Time Screening Test

Subjects will be seated in front of the apparatus and instructed as follows:

"This is a test to determine how quickly and accurately you can respond to different light signals. Use the first two fingers of each hand and rest one finger on each of the four buttons on this box. You see that above each button is a light bulb. Whenever one of these bulbs lights up I want you to press the button underneath it as quickly as you can. This will turn the light off, and my stop clock will tell me how long it took you. Any one of the four lights might blink on after you say 'ready'. When a light does come on, you should only push the button directly underneath it. If you push a different button or more than one it will be a mistake. Ready?"

APPENDIX 4

Personal Data Form

Subject:______________ Name:________________________________

Age:_______ Race:_________ Education:______________years

Visual Acuity:______________________

Height:_______ Weight:_______ Hand Length:________ Hand Breadth:________

Anthropometric Characteristics of the General Army Population (1966)

	Mean	SD	5th Percentile	95th Percentile
Height	68.71"	2.60"	64.49"	73.06"
Weight	159.1 lbs.	23.35 lbs.	126.32 lbs.	201.88 lbs.
Hand Length	7.49"	0.38"	6.90"	8.13"
Hand Breadth	3.5"	0.19"	3.20"	3.83"

MUZZLE CALIBRATION - GROOVING		
Trial	One Hand	Two Hand
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Σ		
$\bar{X}$		

APPENDIX 5

Outline of Training Procedures

A. **Sight Picture**

1. Demonstrate Proper Sight Picture
2. Teach and Practice Weapon Zeroing
3. Center of Mass of the Target
   - Show Paper Targets with CM Marked
4. Practice Obtaining Sight Picture
   - Use One Eye
   - Use Tripod and Calibration Target

B. **Teach Shooting Positions**

1. One Hand, Standing
   - Grip
   - Stance
   - Trigger Squeeze
   - Practice
2. Two Hands, Standing
   - Grip
   - Stance
   - Trigger Squeeze
   - Practice
3. Muzzle Calibration
   - One Hand, Standing
   - Two Hands, Standing

C. **Familiarization Firing**

1. Shooting Situation
   - Target
     - 25 Meters
     - Stationary
   - Time
     - Self-Paced - 3 Rounds
     - Rapid Fire - 3 Rounds, 6 Seconds

2. Firing Session
   - Subjects Wear Red Goggles
   - Appropriate Filter on Pistol (Green)
   - Procedure
     - All Subjects in a Training Group will Receive a Given Test Situation in Rotation before a New Test Situation is Presented
     - Detailed Procedures Prior to a Trial
       - Self-Paced Trial
         - Give Instructions
         - Fire
         - Score Hits and Provide Feedback
       - Rapid Fire Trial
         - Give Instructions
         - Fire
         - Score Hits and Provide Feedback
     - Follow Order of Presentation Protocol on Appropriate Practice Firing Sequence Sheet

APPENDIX 6

Practice Firing Sequences

This Appendix contains samples of the four practice sequences used to familiarize subjects with the shooting characteristics of the various test weapons.

The sixteen subjects were divided into groups of four, and each group was assigned to fire a different "Practice Firing Sequence".

Each firing sequence required the subjects to fire all eight weapon configurations with both the one hand and two hand stances. For each weapon configuration and shooting stance, the subjects fired: 3 rounds self paced fire and 3 rounds rapid fire. Each sequence required the subjects to fire ninety-six (96) rounds.

Practice Firing Sequence I

Subject: ______________________________

Condition	Hits
Moderate grip angle	
Long heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Long light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Short heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Short light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Total	____

Condition	Hits
Extreme grip angle	
Short light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Short heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Long light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Long heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Total	____

TOTAL HITS ________

Practice Firing Sequence II

Subject: ______________________________

Condition	Hits	Condition	Hits
Extreme grip angle		**Moderate grip angle**	
• Short light pull		Long heavy pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Short heavy pull		Long light pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Long light pull		Short heavy pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Long heavy pull		Short light pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Total	____	Total	____

TOTAL HITS ____________

Practice Firing Sequence III

Subject: ______________________________

Condition	Hits
Moderate grip angle	
Long light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Short light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Long heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Short heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Total	____

Condition	Hits
Extreme grip angle	
Short heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Long heavy pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Short light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Long light pull	
1 hand	
Self-paced	____
Rapid	____
2 hand	
Self-paced	____
Rapid	____
Total	____

TOTAL HITS ______________

Practice Firing Sequence IV

Subject: ____________________

Condition	Hits	Condition	Hits
Extreme grip angle		**Moderate grip angle**	
Short heavy pull		Long light pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Long heavy pull		Short light pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Short light pull		Long heavy pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Long light pull		Short heavy pull	
2 hand		2 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
1 hand		1 hand	
Self-paced	____	Self-paced	____
Rapid	____	Rapid	____
Total	____	Total	____

TOTAL HITS ____________

APPENDIX 7

Instructions for Practice Firing

The following instructions were read to a subject each time he prepared to fire a series of three rounds, either self-paced or rapid fire.

1. Self-Paced

"Get into firing position (one or two hand hold). When the target comes on I want you to aim at the center of mass, the middle of the target, and fire. You will get three shots. There is no limit on the amount of time you have to fire the three shots. Try to hit the target in the middle every time. I will tell you how well you shot after the trial is over. Ready? (target on)."

2. Rapid Fire

"This time the target will be on for only six seconds. During that time I want you to aim at the center of mass, the middle of the target, and fire three times. Try to hit the target in the middle all three times. I will tell you how well you shot after the trial is over. Get into firing position (one or two hand hold). Ready? (target on)."

APPENDIX 8

Instructions to Subjects for Test Sessions

"During your training session you shot at a stationary target and this target was always the same size. You are now ready to begin the main part of the experiment.

"From now on you will be firing at different size targets that might appear at any point on the screen, and may or may not be moving, and will disappear after certain periods of time. If you should see a light bar anywhere on the screen you will know that whenever and wherever the target appears it will be moving toward the light bar, and when the target reaches the light bar both the target and light bar will disappear. In these cases the light bar and the target appear at exactly the same time. If no light bar appears on the screen, the target will not be moving.

"Before each trial we will check your firing position to see if you are still in the groove, just as we did during the training session. However, to refresh your memory the procedure is as follows:

- When you are told to do so -- you will step up to the shooting table and pick up the test pistol.
- You will be told which shooting position to assume -- either one hand or two hands.
- Next you assume the proper shooting stance, holding the pistol in the ready position.
- As you assume the shooting stance the experimenter will remind you of the important features of the correct shooting stance.
- When the experimenter requests it -- you are to raise the pistol to the firing position and hold that position while he checks to see that you are in the groove (muzzle calibration).
- When the experimenter indicates that your position is correct you may lower the pistol to the 'ready' position -- pointing it at the reference spot on the lower center of the screen.

"When you have done this and are ready to start you may say 'ready', and the target will be activated. When the target appears, you should, while using your sights, aim as quickly as possible at the center of mass of the target. You should then try to hold your aim as steady as you can on that point in the target and fire to obtain as many hits as possible as long as the target is visible.

"Remember, you are to hit the target as quickly and as often as possible until it disappears!

"Do you have any questions about the procedure or what you are expected to do?"

APPENDIX 9

Experimenters' Procedural Checklists

This Appendix contains sample copies of the procedural checklists used by the two experimenters (E_1 and E_2). The first experimenter (E_1) sat at the experimenters control desk and operated the equipment. E_2 controlled the subject and supported E_1 by performing trial identification and certain manual functions such as setting up the bar light projectors.

At the top of Procedural Checklist E_1, the subject is identified by name and letter code as is the session number. Session 6 here means that this sheet is for the sixth out of sixteen sets of test trials the subject is to perform. The next line indicates that weapon configuration number 7 with the one hand hold will be used during this session. The columns from left to right beginning with Target Start Position indicate the sequence of the tasks he must perform to properly set up the equipment. The alpha numerics indicate the proper control settings for a trial. Handwritten check marks are placed in the blank cells by E_1 as he accomplishes each task and before he procedes to the next task. The Target Condition code uniquely specifies a target condition by range, movement, direction of movement and exposure time. The Trial Number column simply indicates the sequential order of presentation of the various target conditions.

The E_2 checklist is used in much the same manner as the E_1 checklist. The top line shows that the subject is to use the one hand hold. The next line indicates how to identify on film the subject and session number. The Trial Label column indicates how to identify on film the subject and session number. The Trial Label column indicates how to identify each successive trial. The blank columns are for handwritten check marks indicating that a task was completed. The dashes in the light bar setting column indicate that no bar light is required for that trial. The Turntable Setting indicates where the slide projector should be pointing at the start of the trial. For this task E_2 checks to see that E_1 has properly positioned the turntable for the trial and corrects any errors made by E_1. The far right column is for the muzzle calibration check which E_2 performs just prior to the start of the trial.

Procedural Check List (E_1)

Subject: M **Name:** John Doe **Session No.:** 6

Weapon Configuration: 7 **Hold:** 1

Trial #	Target Condition	Target Start Position	✓	Time	Reset	Direction	✓	Motion	✓	Target Slide	✓	Speed	✓	Light Bar	✓	Start	Adv. Print.
1	7	766		4		–		S		2		–		O			
2	2	738		2		L		M		1		3		L			
3	1	242		2		–		S		1		–		O			
4	11	508		4		–		S		3		–		O			
5	5	766		2		–		S		2		–		O			
6	12	390		4		R		M		3		1		R			
7	8	714		4		L		M		2		2		L			
8	9	508		2		–		S		3		–		O			
9	4	970		4		L		M		1		3		L			
10	10	450		2		R		M		3		1		R			
11	3	242		4		–		S		1		–		O			
12	6	602		2		L		M		2		2		L			

PROCEDURAL CHECK LIST (E_2)

HOLD: 1

Subject Code	Slide#	Select	Record	Session Code	Slide #	Select	Record
M	16			6	25		

Trial #	Trial label (Slide #)	Select	Record	Light bar Setting	✓	Turntable Setting	✓	Foot-Muzzle cal.
1.	36			—		2		
2.	37			13		3		
3.	38			—		14		
4.	39			—		8		
5.	40			—		2		
6.	41			5		11		
7.	42			12		4		
8.	43			—		8		
9.	44			15		1		
10.	45			7		9		
11.	46			—		14		
12.	47			10		6		

APPENDIX 10

Pretrial Instructions for Assuming Proper Shooting Position

On every test trial as the subject steps up to the shooting table the experimenter (E_2) verbally reviews the essential features of the proper shooting stance. To accomplish this instruction, a standard line of "patter" evolved for each shooting stance. These lines of "patter" are given below.

<u>One Hand Stance</u>:

- "Feet in Position -- (Pause) --
- Arm Straight -- (Pause) --
- Bring it up - Please (Raise Weapon to Firing Position)
  <u>Note</u>: E_2 Performs Muzzle Calibration Check
- Take It Down -- Indicate When You Are Ready."

<u>Two Hand Stance</u>:

- "Feet in Position -- (Pause) --
- Knees Flexed -- (Pause) --
- Elbows Locked -- (Pause) --
- Palm of the (Right/Left) Hand -- (Pause) --
  <u>Note</u>: Subjects were instructed to support their shooting hand in the palm of the other hand
- Bring It Up - Please (Raise Weapon to Firing Position)
  Note: E_2 Performs Muzzle Calibration Check
- Take It Down -- Indicate When You Are Ready."

APPENDIX 11

Marking/Scoring Rules for Digitizer

1. **Lightspots**

   All lightspots whether they be dots or traces should be marked (digitized) in the apparent center of the dot or trace.

2. **Hit or Miss**

   A shot is a hit if the apparent center of the dot or trace is in the target or touches any part of the target outline.

3. **Shot Pulses (Cannonball)**

   When shot pulses appear on two frames in succession - use the first frame to mark (digitize) the shot - regardless of how dim the shot pulse appears.

4. **No Visible Dot or Trace**

   a. Before First Shot

   If while digitizing the pre-first-shot frames, you lose the dot/trace for a frame or two, proceed to the next frame where it is visible. However, if you lose more than two frames in succession, you probably weren't tracking the right dot/trace. In this case, DELETE all preceding "P" lines on the TWX printer and begin a new set of pre-shot lines when you find a dot/trace of which you are sure.

   b. After First Shot

   If on a time frame or a shot frame, the dot or trace is not visible, proceed to the next frame and digitize the dot/trace location. However, if a time frame is involved, maintain the original every fourth frame scheme. If for some reason you cannot find the dot/trace on the succeeding frame (i.e. for two successive frames), go back to the frame just preceding the data frame of interest and digitize that dot/trace.